Vol. 1 OCTOBER, 1918 No. 10

Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries.

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Published Monthly by the
AMERICAN CERAMIC SOCIETY

Publication Office
211 Church St., Easton, Pa.

Editorial Office
Rutgers College, New Brunswick, N. J.

SIX DOLLARS PER YEAR (Foreign Postage Additional) *SINGLE NUMBERS, SIXTY CENTS*

Entered as second-class matter, July 15, 1918, at the post office at Easton, Pa., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized August 16, 1918.

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JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly journal devoted to the arts and sciences related to the silicate industries.

Vol. 1 **October, 1918** **No. 10**

EDITORIALS.

IMPORTED CLAYS.

With the signing of the armistice there appeared to be a cessation of the agitation of many months past in reference to the importation of the clays of different kinds. Undoubtedly with the closing of hostilities many of our manufacturers began to look with longing eyes to a fresh and adequate supply of the imported materials, especially those used in the manufacture of the white burning pottery products. Nor were they doomed to disappointment as we have already learned of an increased flow of the imported clays.

That the efforts of our geologists and laboratories have not been fully rewarded in the location and development of new and adequate deposits of white burning clays of first quality is to be regretted. Let us hope that there will be no let-up in their efforts and that the field and laboratory searches will be continued.

Doubtless the situation as regards the importation of clays for crucible, pencil and glass pot manufacture will remain the same for some time to come. American clays in glass pot mixtures appear to be giving very good satisfaction and the production of clays for this purpose appears to be on a well established basis. The results secured with American clays in graphite crucibles are showing steady improvement, and it is to be hoped that our crucible manufacturers will never again be dependent upon the foreign deposits for this highly important commodity in their industry.

THE POTTERY INDUSTRY.

When viewed as a whole, there has not been a marked change in the quality and general nature of the pottery wares manufactured in this country during the years of the war. It is true that we have long excelled in the quality of certain of our pottery manufactured products, especially of a structural nature such as electrical porcelain, sanitary ware, etc. In a general way, however, the bulk of our wares is of the same quality as before the war.

Our pottery manufacturers still cling to the use of ball clays. True, the elimination of ball clays from body mixtures involves more or less radical changes in methods of molding, burning temperatures, etc. So long as the ball clays are used, however, it will not be possible to produce wares which compare favorably in color and cleanliness with the hard porcelains of Continental Europe. We do produce in limited quantities wares which are not inferior in appearance and quality to the best of the imported wares. Our wares of this kind, however, must be classed as art wares and cannot compete in price with the bulk of the table wares which were imported in large quantities previous to the war and sold at amazingly low prices in competition with the American-made pottery.

Will our manufacturers be satisfied to return to the former conditions of competition or will their efforts to raise the standard of quality be stimulated? It is to be hoped that the technique of this branch of the pottery industry will keep pace with the advancement made in some of the smaller and less important branches.

ORIGINAL PAPERS AND DISCUSSIONS.

A DISCUSSION OF TERRA COTTA DRYERS.

By Ellis Lovejoy, E.M., Columbus, O.

As we recall the various terra cotta dryers we have examined and designed, the thought comes to us that the manufacturers of terra cotta have not come to any system in dryers; that the dryers used differ widely in character and efficiency; that the ware, built up from several clays and grog, will stand severe treatment in the simple shapes and only the large and complicated shapes require more careful treatment; and finally that increasing competition will require the manufacturers to adopt more economical methods of drying and burning.

There are in use several ordinary waste-heat car tunnel progressive dryers. The waste heat progressive dryer holds a prominent place in the clay industries. It uses the heat of cooling kilns and that of engine exhaust, and, in consequence, it is economical in fuel. The dryer conditions seem to be ideal. The ware enters a humid low temperature atmosphere and as it advances, the humidity decreases and the temperature increases, until finally near the exit it is subjected to upward blasts of hot air through the floor ports. It is desirable in the manufacture of terra cotta that each lot of ware come through about the same time and where there are a number of tunnels this condition is fairly well met. The operation of the dryer is not so ideal as it would appear. As long as the operation is continuous the conditions in the tunnels are constant, but continuous operation is not customary. There is a forward movement of the heat and a drop in humidity in the tunnels during the night when the ware is not moving, and a corresponding retreat in the daytime when the tunnels are

being emptied and filled. This variation in the tunnel conditions may be withstood by the margin of safety in the drying behavior of the ware. The tunnel conditions vary much more widely over holidays and some wares may not stand this variation, but stopping the fans during all or part of the period may give sufficient control. Thus far, however, the progressive tunnel may be said to meet the requirements.

There is a more serious objection. It is impractical to so load the cars with terra cotta as to closely fit the tunnels. Almost invariably there is excessive space between the tunnel roof and the top of the ware and the air rises into this space. Since the air movement beyond the hot air zone in the tunnel is horizontal, the top of the ware, or the top ware, is subjected to maximum drying conditions while very little drying progress occurs in the bottom. When the cars reach the hot zone the bottom green ware is subjected to the severe conditions imposed by the blasts of hot air coming through the air ports and it is to this ware in this zone that great damage is likely to occur. It is readily seen that the top ware is safe in the hot zone because of its advanced condition and its position relative to the air blasts. It frequently happens that the top ware is damaged in the early stages near the receiving end and this is often attributed to a lack of humidity, but it is our opinion that it is more often due to unequal drying.

The users and advocates of the progressive tunnel may say that the ware readily withstands these conditions and that the dryer is satisfactory. We wonder how far this is true. If there is no loss in either dryer or kiln there can be no question in regard to the efficiency of the dryer and the operators are to be congratulated on the strength of the body which they have developed, but this is not conclusive, and one is not warranted in adopting such a dryer as the best for the product in general. In other lines of ware we have too frequently seen the weakness of the progressive dryer to be convinced that it is the best type for the manufacture of terra cotta.

In drying other wares we have found a decided improvement both in the rate of drying and in the per cent of perfect output by extending the hot air duct nearly or quite the full length of the tunnel and thus securing up-draft through all the ware. At first

glance this seems more severe than the original type, and on the whole it may be so, but the ware is subjected to more uniform conditions. The temperature of the air is lowered by wall and ground absorption as it advances in the lower duct, and with graduated floor slots the conditions at the car receiving end may be materially less severe than at the delivery end. We still have the forward movement of air in the tunnels with increasing humidity, and there will be decidedly more circulation in consequence of the upward currents into the horizontal current. We have seen terra cotta regularly subjected to decidedly more severe treatment, and while this ware may have been exceptional in its drying behavior, yet the fact that it is a prepared body heavily grogged leads us to believe that it will generally stand more severe drying tests than many of the common wares made from a single clay.

The chief weakness of the usual progressive tunnel is lack of circulation. We dry and harden the top ware without getting drying conditions down into the mass of ware. If the ware will stand the direct up-draft heat the full length of the tunnel as above suggested, an economical dryer for terra cotta is a simple problem, but if not then we must improve the operation of our present type by better circulation, or in other words, break up the horizontal current of air in the top of the tunnel and drive it down among the ware.

The value of circulation is remarkably demonstrated in recent dryers nor is the idea new.

It seems to us that in the progressive dryer, the operation could be in two stages. Make the delivery (hot) end as in the usual progressive tunnel, then midway, or less than midway, of the tunnels put a cross duct on top of the tunnels, similar to the under-ground hot-air duct at the delivery end, with an opening through the bottom of this duct (tunnel roof) into each tunnel. Draw the air from the tunnels by means of a fan and return it to the tunnels through a second cross duct and lateral ducts on top of the several tunnels. In other words, duplicate on top of the tunnels from the center to the receiving end, the duct system at the delivery end, except that the air for the receiving end would be drawn from the tunnels themselves instead of from

cooling kilns or through steam coils. The partially to nearly dry ware in the delivery end will be subjected to *upward* blasts of hot dry air. From the center to the receiving end the green ware will be subjected to *downward* blasts of lower temperature higher humidity air in which the temperature decreases and the humidity increases toward the end. In such a construction we retain all the ideal features of the progressive tunnel and overcome the very serious horizontal over-draft difficulty without any increase in fan equipment of the modern two-fan dryer.

A progressive tunnel equipped with steam coils only and making no use of waste kiln heat is, or soon will be, economically out of the question. In our opinion the most essential economy in the future of the business is the use of the heat from the cooling kilns for drying even though the future factory makes use of the continuous or car tunnel kiln.

The box systems in use in several factories, it seems to us, are far from satisfactory and are not economical. The ware is set in a closed room. Blasts of air are turned into the room and, by one means or another, directed to an exit. The treatment is severe, and the heat waste excessive. The air volume and consequent heat supply is practically constant, while the moisture removed passes from a maximum to virtually zero. At the end of the drying we are heating a large volume of air and forcing it through the dryer without any return whatever. A better operation is to return the air to the fan, replacing some loss with fresh air. Thus we get the humidity conditions and at the same time conserve the heat. The usual equipment is the steam coil with exhaust steam in the day and live steam at night. So far as we know, waste heat from cooling kilns is not used, perhaps because of the greater ease in regulation of the temperature and also because the profits of the business have not insisted on economies. The introduction of kiln heat into a factory building not fireproof involves a questionable fire risk although a number of sewer pipe factories have made such use of it.

The humidity treatment is nicely carried out in the regenerative type of tunnel dryer. The tunnel is two storied. In the upper tunnel, or duct, are steam coils, with a fan at one end. The lower tunnel is filled with cars of ware. The two tunnels are connected

at each end. When the cars are placed, the doors closed and the fan started, the fan picks up the air from the lower tunnel, drives it through the coils to the opposite end of the upper tunnel, then down into the lower tunnel and back among the ware in the lower tunnel to the fan. Thus we have a complete cycle repeating ad libitum. It is necessary, of course, to provide a vent for the escape of some of the saturated air and replace it with fresh air through an inlet to the fan, and this may be extended to the extent that all the intake air is from the outside without any regeneration. The number of such dryers is too limited to draw any conclusion. It is in a class with the regenerator box dryers with the handicap of multiple fans and horizontal air movement. Steam supplies the heat, and live steam so far as we know, but there is no reason why exhaust steam may not be used. It is not practical to use waste kiln heat in connection with regeneration and natural humidity except by the use of an economizer equipment which would be expensive in initial installation and maintenance. There is, however, an excess of waste kiln heat and no occasion for regeneration except to get natural humidity. Humidity could be obtained in other ways than from the ware, but it requires regulation and risk not involved in the natural operation. It is inconceivable, especially if the tunnels are short, that moisture taken from the ware in exchange for heat could saturate the air to the extent of the dew point, whereas careless artificial humidation might easily saturate in excess of the dew point and result in considerable damage to the ware.

We have in this regenerative tunnel dryer the same difficulty of horizontal air movement over the top of the ware without satisfactory circulation around the ware as in the progressive car tunnel and in greater degree in that there is no upward movement as in the delivery end of the progressive tunnel. The horizontal movement can be broken up by a duct between the upper heating tunnel and the lower drying tunnel, with ports into the latter. Thus the air from the upper heating tunnel would return through this delivery duct and be blown down, on the ware, through the graduated ports in the under side of the return duct. As stated above, we do not believe that the air naturally could be saturated to excess in the original construction, but should it be possible,

the use of the return duct delivering hot air at intervals from end to end of the tunnel would greatly lessen the possibility.

The return duct could be eliminated and graduated ports be placed in the division floor between the two tunnels and thus simplify the construction, provided the steam coils are at one end of the upper tunnel.

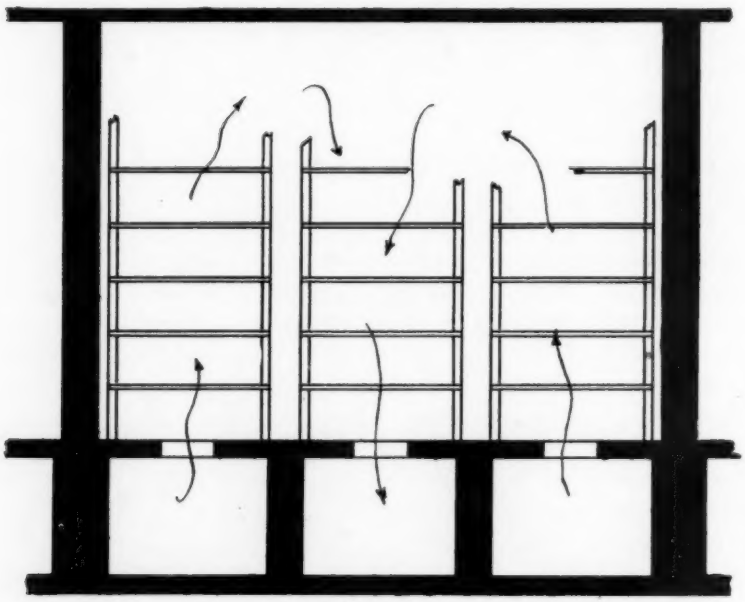

FIG. 1.

Another idea would be to place the return duct under the lower tunnel floor and blow the air upward among the ware, thence horizontally to the end of the tunnel and into the fan, but this involves an awkward connection between the heat tunnel and delivery duct.

The only advantage that we can see in the double tunnel in its original form over the usual progressive tunnel is that it may be limited in length and thus better adapt itself to many factory layouts, and in that the humidity conditions are probably more satisfactory. Its fuel cost in live steam and multiplicity of fans give a balance in favor of the progressive waste heat tunnel.

A recent innovation in tunnel dryers, not as yet, however, applied to terra cotta, has a wide tunnel with three under-floor ducts as shown in the sketch. (Fig. 1.) The two outside ducts supply the hot air from the cooling kiln and the central duct is the exhaust. The hot air rises among the ware on pallets over the side ducts and passes down among the ware over the central duct. The central duct could be used for hot air and the side ducts for exhaust or two ducts could be used instead of three,—one for hot air and one for exhaust. If all the ware will stand the direct heat, that slowest in drying could be placed over the hot air ducts and the quick drying ware over the exhaust duct. Since the outgoing air would have greater humidity than the incoming air, the ware over the exhaust would be retarded in its drying. Another view would be to place the safe drying ware over the hot air ducts and the difficultly drying ware over the exhaust duct. This would require a longer drying period but insures greater safety, and in some degree gives humidity for the more difficult ware. If a more complete humidity operation were required, the moisture would have to be introduced into the incoming hot air and reduced as the drying progressed.

One's first thought would be the possibility of short circuiting from the hot air ducts to the exhaust duct, but this would be easily overcome with the foot-pallets in use in a number of factories. The tunnels would be roomy and satisfactory for motor trucks. The danger of short circuits with cars would be greatly increased, and it probably would be necessary to have a curtain wall between the cars which would insure the full up- and down-movement. The feature of the dryer is the circulation, and there are no restrictions in regard to length, except that excessive length decreases the chances of getting uniform exhaust from end to end. This problem is less difficult and more easily solved in a dryer than in rectangular kilns where we have in some installations end-draft up to ninety feet in length.

Floor drying as in sewer pipe factories, with covers to get humidity, increases the floor space required, heats the working space unduly and increases the humidity therein, and finally requires live steam in a large measure. It has the advantage that the ware can be watched and the drying of individual pieces controlled,

but the manufacture of terra cotta is no longer the modeling of lions rampant and recumbent, of decorative friezes and capitals. The bulk of the ware is in small pieces duplicated indefinitely and the need of an independent dryer to take the ware from the floor is imperative.

Ducts from the kilns or boilers under the pressing floors are in use but in our opinion are questionable, and blowing hot air into the press room at night from kilns or steam coils is not a satisfactory drying system. "Better working conditions" are the basis of many labor disputes and often times justly so, and factory operations must meet these conditions. Where it is necessary to hold the ware on the floor until it is fully set (leather hard) it would be better to provide a steam heated slatted floor for this preliminary drying, or in case it is not desirable to move the ware at all, then after filling one section of the floor, move the pressmen to another section and turn steam into the pipes under the first section, or use steam only at night. It is not our purpose to discuss sanitary factory conditions which have no bearing on subsequent drying, except as the factory is the dryer. We are of the opinion that a properly developed independent dryer with suitable control will eliminate much of the hot floor press room drying.

The wide divergence in dryer types indicates that terra cotta manufacturers have not solved the dryer problem.

The essentials are waste-heat, thorough circulation and controllable humidity. We do not know of any dryer which includes all of these. In some instances humidity is of less importance. This leaves waste-heat and circulation to be combined, yet simple as the problem is, we have not seen the solution of it in operation in any terra cotta factory.

THE COMPOSITION OF CHINESE CELADON POTTERY.

By J. S. Laird.

The raw materials used in the modern ceramic industry in China, together with the compositions of the bodies, glazes, and colors employed, have been studied very thoroughly by the ceramists of the Sèvres potteries, Ebelman and Salvetat,[1] in 1850, and Vogt[2] in 1890. The latter investigator has confirmed his results by preparing from European materials bodies exactly corresponding to the Chinese, and has reproduced many of the famous glazes, including crackle ware and flamed red or sang-de-boeuf.

Our knowledge of old Chinese pottery is much less complete. Very few specimens have been examined scientifically as their value as works of art and antiques has discouraged the destruction incidental to chemical analysis. In the hope of obtaining valuable data on this subject an examination of the sites of the ancient kilns at King-to-chen was undertaken a few years ago by Mr. Charles L. Freer of Detroit, the well known collector and authority on Chinese pottery. Internal troubles in China have up to this time made excavation of the kiln sites impossible. Two interesting specimens were, however, obtained and examined analytically. These partial results are reported in this article.

Specimen 1.—This specimen consisted of a lump of glaze which had dripped off the ware in firing and solidified on the kiln floor. While it was undoubtedly old, its exact date has not been fixed. It was a solid, homogeneous lump, in color bluish green or "celadon" with reddish streaks. Where it had hardened on the kiln floor it had picked up particles of sand. These particles were carefully ground off the sample taken for analysis.

Specimen 2.—The second specimen obtained was a small plate or saucer about five inches in diameter. It probably belonged to the Yuan period and showed its antiquity by a marked weathering. The body of this plate was fairly dense and fine grained,

[1] Ebelman and Salvetat, *Ann. chim. phys.*, **313**, 257.

[2] Vogt, *Bull. soc. encour.*, **99**, 530.

but soft enough to be easily scratched by a knife. It was light colored, inclined to buff with reddish streaks. Its composition and appearance would class it as a fire clay and not a kaolinitic body.

All but the foot of this plate was covered with a thick opalescent bluish green glaze showing a small uniform crazing. It was sufficiently opaque to completely hide the body of the ware. A blotch, shading in color through bright red and green to black, marked a spot where apparently a cinder had fallen on the ware during the firing. Sufficient of the glaze for analysis was removed by careful chipping with a small chisel, and thanks to the thickness of the glaze it was possible to obtain a sample entirely uncontaminated by fragments of the body. It was not possible to obtain separate samples of the red or green portions.

The analyses of these two glazes and of the body of the plate are given in Table 1.

TABLE 1.

	Glaze 1 (lump).	Glaze 2 (plate).	Body (plate).
SiO_2	72.52 per cent	66.40 per cent	63.20 per cent
Al_2O_3	10.59	13.88	28.30
Fe_2O_3	0.41	0.30	3.47
FeO	2.02	1.19	...
CaO	8.48	11.58	2.05
MgO	1.24	1.61	trace
K_2O	3.77	4.25	1.98
Na_2O	1.48	1.84	0.37
MnO	trace	trace	trace
TiO_2	trace	trace	trace
P_2O_5	0.21	..	trace
	100.72	101.05	99.37

Except for the presence of iron, these glazes are closely related to the cone 4 type of whiteware glazes and are quite calcareous, No. 2 being even higher in CaO + MgO than the cone 4 formula.

Color of the Glazes.—It will be noted that the only coloring oxides present in the glazes in appreciable amounts are oxides of iron, particularly ferrous oxide. The presence of the oxides commonly employed to give blue or green colors—copper, cobalt and chromium—could not be detected by the most careful tests. When

particles of these glazes were remelted in an oxidizing atmosphere they became almost colorless. Vogt[1] found that the blue-green color of modern celadon glazes was developed only when the ware was fired in a strongly reducing atmosphere, otherwise a pale yellow was produced. Compounds of ferrous iron must therefore have given the color of these glazes, the peculiar opalescence being due probably to the high percentages of lime and alumina.

Comparison with Other Reports of Celadon Glazes.—Meyer[2] has reported analyses of the body and glaze of an old celadon vase brought from China, and Ebelman and Salvetat[3] and Vogt[4] analyzed modern celadon glazes and the bodies on which they

TABLE 2.

Chinese bodies used with colored (celadon) glazes.

Ware. Analyst.	1. Yuan. Laird.	2. Old Chinese. Meyer.	3. 1850. Salvetat-Ebelman.	4. 1890. Vogt.
SiO_2	63.20	69.51	69.0	69.50
Al_2O_3	28.30	22.72	23.6	23.10
Fe_2O_3	3.47	1.84	1.2	2.00
CaO	2.05	0.27	0.3	0.16
MgO	trace	0.36	0.2	0.22
K_2O	1.98	4.79	3.3	3.72
Na_2O	0.37	0.87	2.9	1.12
	99.37	100.36	100.5	99.82
Celadon glazes used on these bodies.				
SiO_2	66.40	64.98	72.00	70.2
Al_2O_3	13.88	14.33	6.00	14.8
Fe_2O_3	0.30	1.39	2.50	1.5
FeO	1.19	....	....	...
CaO	11.58	10.09	10.40	8.1
MgO	1.61	1.55	trace	0.2
K_2O	4.25	5.61	9.10	3.2
Na_2O	1.84	0.81		2.1
TiO_2	trace	1.39	trace	trace
MnO	trace	trace	trace	trace
	101.05	99.15	100.00	100.1

[1] Vogt, *Loc. cit.*

[2] Meyer, "Der Alter Seladon Porzellan," 1885.

[3] Ebelman and Salvetat, 3rd Memoir.

[4] Vogt, *Loc. cit.*, p. 562.

were used. According to the latter, the body was prepared from an impure dark-burning kaolin softened by the addition of micaceous pegmatite. The glaze was a combination of the pegmatite with iron-bearing clay and milk of lime, the lime having been ignited several times with fern fronds. This corresponds with the description given by Pere d'Entrecelles two hundred years ago in the first reports sent to Europe of the ceramic art in China.

These analyses are combined with the analyses of this piece of very old Chinese pottery in Table 2. The analyses are quoted from the article by Vogt as the original papers are not available.

From the higher percentages of iron, lime, and alumina, and lower percentages of alkalies, it would seem probable that a natural clay and not a modified kaolin had been used in the body of the Yuan pottery. Ferrous iron is not reported in any of the other analyses, probably because no attempt was made to determine the state of oxidation of the iron present. Otherwise the composition of the two oldest glazes are quite similar, and do not differ greatly from the most modern. It is quite interesting that without the aid of accurate methods of analysis, in fact, depending in their selection of material largely on visual inspection, the Chinese potters have controlled the composition of their glazes within very narrow limits over a period of probably ten centuries.

UNIVERSITY OF MICHIGAN,
ANN ARBOR, MICH.,
December 14, 1918.

THE HYDRAULIC PROPERTIES OF THE CALCIUM ALUMINATES.[1]

By P. H. Bates, Pittsburgh, Pa.

Introduction.

The Pittsburgh Branch of the Bureau of Standards has been conducting several investigations dealing with the hydraulic properties of all of the compounds in the lime–alumina–silica system. These have been carried on in connection with a general investigation of portland cement. It will be recalled that the compounds of this system are:

$CaO.SiO_2$	$3CaO.Al_2O_3$	$Al_2O_3.SiO_2$	$CaO.Al_2O_3.2SiO_2$
$3CaO.2SiO_2$	$5CaO.3Al_2O_3$		$2CaO.Al_2O_3.SiO_2$
$2CaO.SiO_2$	$CaO.Al_2O_3$		$3CaO.Al_2O_3.SiO_2$
$3CaO.SiO_2$	$3CaO.5Al_2O_3$		

Some of these exist in several forms, notably the dicalcium silicate or orthosilicate, which can exist in four—depending upon the manner in which it is melted or the temperature from which it is cooled.[2]

Such an investigation should be of considerable interest and should furthermore be carried on in connection with a similar one dealing with portland cement, because, while it does contain materials other than lime, alumina or silica, these form ninety per cent or more of this important structural material. At the same time, the limits within which its composition may vary cover but a small part of the total area of the ternary system. This restricted composition of portland cement is the result of evolution, that is, it has been found by years of trial that a cement of about the average composition of commercial brands can be more economically made and gives better results

[1] By permission of the Director, Bureau of Standards. Read at the December, 1918 meeting of the Pittsburgh Section of the American Ceramic Society.

[2] Rankin, "The Ternary System Lime–Alumina-Silica," *Am. J. Science*, **39**, Jan., 1915.

in application than others having materially different compositions. Thus the natural cements, containing frequently very high amounts of magnesia or widely varying amounts of silica or alumina, could be produced more cheaply but require longer periods of hardening in order to develop strength equivalent to that of the portland cements. Under certain conditions slags also develop slowly but ultimately very satisfactory hydraulic properties. But even the area embraced by the compositions of these three materials (portland and natural cements and slags) covers but a small part of the area of the system. Therefore, the entire system offers fields for exploration to see if any other portions of it contain compounds which under the action of water possess the property of hardening either in air or water, and whether after such hardening they remain either weather-resisting or are able to resist the further action of water. These two properties, especially the latter, constitute "hydraulic properties."

While it has not been possible to produce all of the compounds of the system in the desired amounts and purity, the entire system has been covered by burnings on batches having compositions very similar to those of all of the different compounds. It was found that the following alone developed hydraulic properties: $2CaO.SiO_2$ (β-form); $3CaO.SiO_2$; and all of the aluminates except the tricalcium aluminate. The fact that the tricalcium aluminate, the only aluminate present in portland cement of normal composition and burning, does not have the desired hydraulic properties is very striking. At the same time one is impressed just as much by the fact that the other aluminates of lime all have this property of hardening and acquiring at early periods strengths in excess of those acquired by portland cement at the end of an equal period. The aluminates are, therefore, worthy of especial consideration and the remainder of this paper will be given over to a brief discussion of their production, their properties, and the chemistry of their hardening.

$3CaO.Al_2O_3$.

The tricalcium aluminate ($3CaO.Al_2O_3$) can be prepared in a pure condition with some difficulty. It decomposes at about

1535° C into CaO and liquid. If this decomposed material is reground and reburned at a temperature of about 1350° C for several hours, it is possible to secure the aluminate free from any CaO. This ground pure tricalcium aluminate, on the addition of water, agglomerates into masses, the exteriors of which alone are hydrated. At the same time there is a vigorous evolution of heat—the mass giving off steam copiously. By grinding in a mortar it is possible to secure a fairly smooth paste free from a great amount of the hard agglomerated granules of the material which have not been acted upon.

If pats of this paste are placed in a damp closet, they seem to acquire both an initial set (in about three hours) and a final set (in from 48 to 72 hours). But if the interiors of the pats are examined they will be found to be quite soft, and frequently, if they are allowed to remain in a damp closet for about a week, they become very soft throughout. If placed in water they disintegrate completely. The product of hydration is hydrated tricalcium aluminate, which is at first in a colloidal (gelatinous) form but is rapidly converted into a crystalline form.

The question naturally arises—does this tricalcium aluminate act in a similar manner in normal portland cement? If so, what masks or retards this action—which apparently does not take place when cement is gaged with water? If it does not, what is there in the cement which so modifies the properties of the tricalcium aluminate so that it appears to have hydraulic properties?

Before considering these questions, it is well to remember that alumina (Al_2O_3) is not required in portland cement—except to make it possible to produce it on a commercial scale. A cement having all of the properties of portland cement and containing less than one-half of one per cent of alumina can be produced. A cement of this kind, however, cannot be produced in a rotary kiln or at a temperature which would make its production a commercially feasible proposition. In the manufacture of portland cement the presence of alumina is necessary to the lowering of the temperature of burning to such a degree that a ternary system may be formed (without too great an expenditure of heat) and from which the tricalcium silicate—the active hardening constituent—may separate.

If a section of portland cement clinker is examined it will be noticed that the constituents do not have a well-defined outline nor are they separated into well-defined crystals. The dicalcium silicate—the major constituent—exists in fairly large grains which blend off into a more or less homogeneous boundary containing the tricalcium aluminate and tricalcium silicate as a bonding material. Although in a well-burned clinker having a high silica content the tricalcium silicate does exist in well-defined crystals, it should be remembered that such a clinker is an exceptional one. It can be readily seen, therefore, that in ground clinker the grains will not be separate grains of any one constituent, as they would be in a mechanical mixture, but that even the finest grains possibly contain some of all of the constituents. Consequently, the activity of the tricalcium aluminate will be retarded to a degree by the inability of the water to reach all of its surfaces. Although what would be its normal activity in the pure condition is thus reduced to certain degree, the other active constituent of the cement—the tricalcium silicate—is being acted upon by the water and the lime is going into solution. This latter very materially modifies the activity of the tricalcium aluminate. If this aluminate in the pure condition is mixed with hydrated lime, in amounts not exceeding 10 per cent, and be then gaged with water, a very smooth, plastic paste, which hardens in air quite similarly to portland cement, is obtained. This action is strikingly different from that of water on the tricalcium aluminate when hydrated lime is not present. It will be recalled that in the latter case a smooth paste was not obtainable, nor one which would harden—on account of the almost instantaneous action of the water and the production of a granular paste composed of grains of unhydrated material protected on their exteriors by a film of hydrated material.

It appears, therefore, that in portland cement the tricalcium aluminate does react to a degree in a manner similar to its action in the pure condition, but that this activity is reduced to a limited degree by the inability of the water to reach all of its surfaces and is masked by the presence of a preponderance of the more slowly acting silicates. The action is also very materially modified by the presence of lime. The latter may have been either

originally present in the cement in the uncombined condition or freed by the water from the tricalcium silicate.

In view of the fact that the tricalcium aluminate, in the pure condition, does not have any hydraulic properties and cannot be readily gaged with water, no test specimens were made for determining its tensile or compressive strength.

$5CaO.3Al_2O_3$.

There is no great difficulty in preparing $5CaO.3Al_2O_3$. This aluminate when ground reacts so energetically with water that it cannot be readily handled. Some heat is also evolved, but not in the amounts evolved by the tricalcium aluminate. In order to retard somewhat the rapidity of the hydration and thus to permit the molding of the gaged material, it is necessary to use an excess of water. This results in low strengths. If about 3 per cent of ground gypsum is mixed with it, a smaller amount of water is required. The strength in this latter case compares very favorably with that developed by portland cement after the same period of ageing. The products of the hydration of this aluminate are hydrated tricalcium aluminate and hydrated alumina, in other words, during the hydration, alumina splits off and separates as gelatinous hydrated alumina. On account of its rapid set, little further work was pursued with it. Several small burns were made of it although there were no attempts to secure a quantity sufficient for the preparation of neat, sand, or concrete test specimens.

$CaO.Al_2O_3$ and $3CaO.5Al_2O_3$.

Burnings of small quantities of $CaO.Al_2O_3$ and $3CaO.5Al_2O_3$ showed that both of these set slowly and harden rapidly and attain such high strengths that it was deemed advisable to make burns in a rotary kiln and in sufficient amounts to make concrete specimens for long-time tests. It was also thought advisable to determine the effect of such impurities as silica and iron oxide on the mineralogical composition and on the physical and chemical properties. Eight burns were made, the analyses of the products of which were as follows:

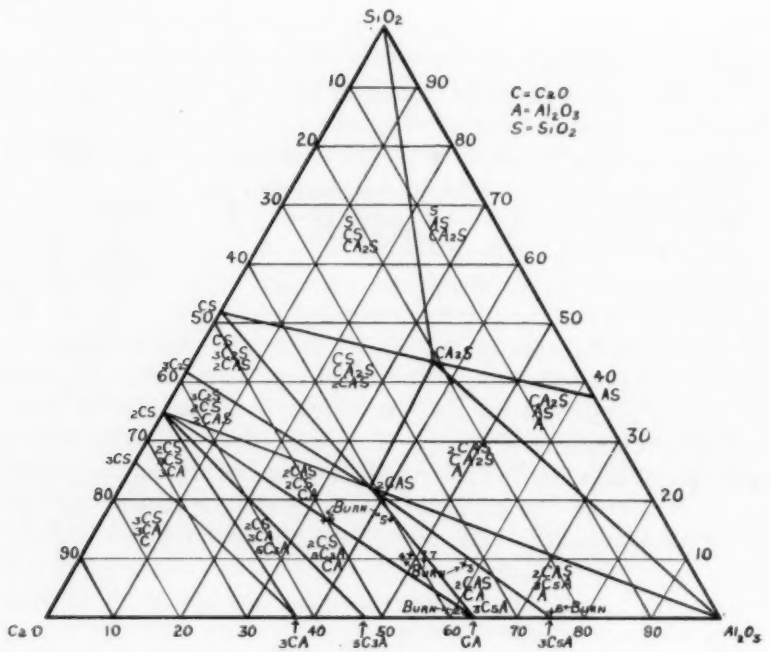

FIG. 1.—The location of the burns (Table 1) in the ternary system; also the fields showing the final products of crystallization according to Rankin.

TABLE 1.

Burn No.	1	2	3	4	5	6	7	8
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	0.44	0.76	9.41	10.48	17.23	17.38	11.33	0.68
Al_2O_3	62.31	61.25	55.09	46.71	39.96	30.52	47.06	74.11
Fe_2O_3	0.51	0.60	2.04	2.13	2.57	1.85	3.10	0.40
CaO	36.69	36.32	30.73	39.79	38.84	46.72	34.87	23.82
MgO	0.36	0.48	2.95	1.04	1.29	2.27	3.66	0.81
Ig. loss	0.07	0.50	0.08	0.32	0.14	0.78	0.17	0.38
	100.38	99.91	100.30	100.47	100.03	99.52	100.19	100.20
Temperature of burning °C	1460°	1480°	1490°	1380°	1455°	1360°	1445°	1500°
Constituents[1]	$3C_5A$	CA	CA	2CAS	2CAS	2CS	2CAS	CA
	CA	$5C_3A$	$3C_5A$	CA	CA	$5C_3A$	CA	$3C_5A$
	2CS	2CS	2CAS	2CS	2CS	CA	2CS	2CAS

[1] Note C = CaO. A = Al_2O_3. S = SiO_2.

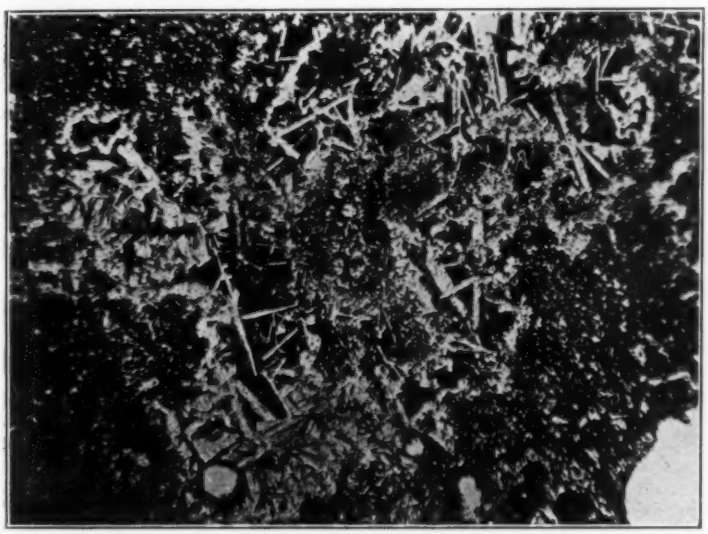

FIG. 2.—Some of the burns produced clinker rich in crystals of $2CaO.Al_2O_3.SiO_2$ and $3CaO.5Al_2O_3$. These cannot be distinguished in thin sections; usually the binary compound predominated. This figure is a photomicrograph of a thin section of clinker from Burn No. 5. Mag. 90x.

It is of more than passing interest to note that this work was started and the petrographic examination of the clinker was made by Mr. A. A. Klein, former petrographer of the Bureau of Standards, before the paper by Rankin[2] of the Geophysical Laboratory, giving the fields of stability of all of the compounds of this system, appeared. We were very gratified upon noting in this report that the compounds found in these clinkers by Klein were those that should occur from their composition—according to the results of Rankin (see Fig. 1).

There was no particular difficulty in making any of these burns with the exception of Nos. 4 and 6. Both of these batches had low melting points and consequently had a marked tendency to form "logs" or "balls" in the kiln. In the case of No. 6, a very slight increase in the temperature produced a slag. On

[2] *Loc. cit.*

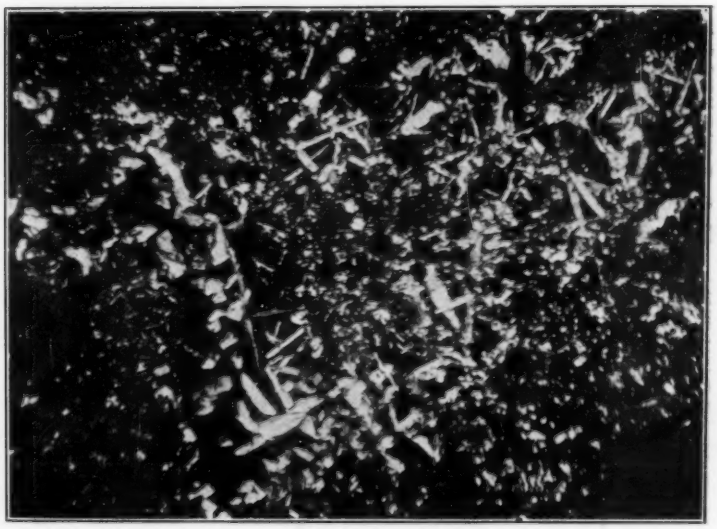

FIG. 3.—The same as Fig. 2, but the Nicol prisms of the polarizing system were crossed.

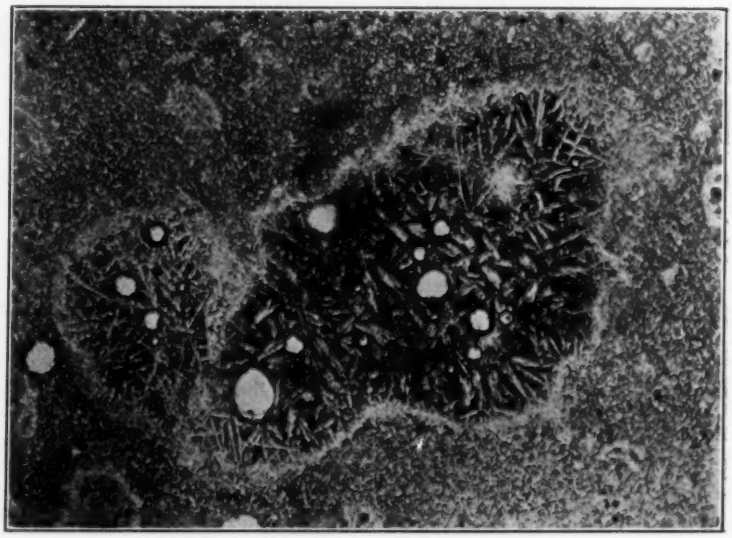

FIG. 4.—Photomicrograph of a thin section of the clinker from Burn No. 3. Mag. 50x.

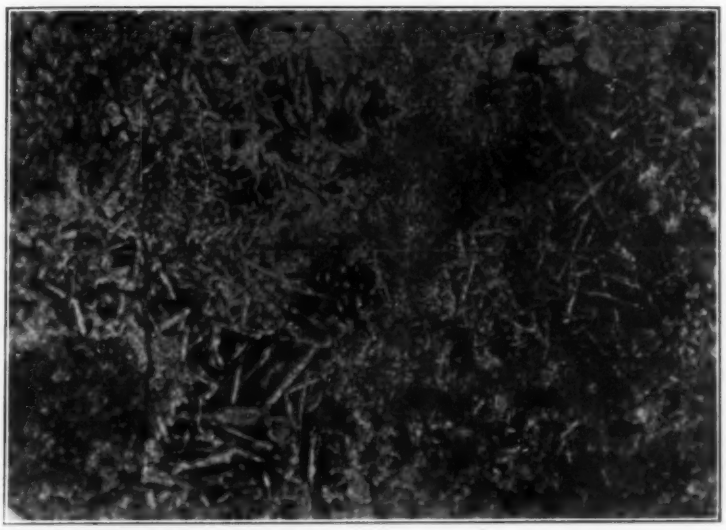

FIG. 5.—Photomicrograph of a thin section of the clinker from Burn No. 7. Mag. 140x.

account of this low fusion temperature, the β-form of the orthosilicate was not stable and the clinker had a tendency to crumble or dust. This is caused by the inversion of the β-form of the silicate to the γ-form—which is accompanied by an increase in volume of about ten per cent. The material from burn No. 4 crumbled into pieces which were about a quarter of an inch in diameter, while the material from No. 6 was reduced almost completely to a very fine powder. If pieces of the clinker of the latter burn were removed from the hotter parts of the kiln and cooled quickly, the dusting was entirely prevented. The other mixes formed at the temperatures show very satisfactory clinker, the first two (Nos. 1 and 2) and the last ones (Nos. 7 and 8) producing white clinker similar in appearance to that produced in the burning of white portland cement. The structure of some of the clinkers is shown in Figs. 2, 3, 4 and 5.

The times of set of the cements from the above burns as determined by the use of the Gilmore and Vicat needles were as follows:

TABLE 2.

Burn No.	Initial set. Gilmore. Hours.	Minutes.	Vicat. Hours.	Minutes.	Final set. Gilmore. Hours.	Minutes.	Vicat. Hours.	Minutes
1	0	55	0	25	4	45	2	10
2	0	40	0	5	3	50	0	50
3	6	25	5	15	*	*	7	5
4	0	35	0	10	3	30	1	15
5	0	40	0	15	4	45	3	15
6	0	7	0	2	0	45	0	12
7	6	0	3	45	*	*	*	*
8	7	0	*	*	*	*	*	*

* = set between 8 and 24 hours.

The time of set, when studied in connection with composition and constitution, reveals the fact that the mixes low in lime and high in alumina are those which set more slowly. The cement from burn No. 8, which approaches the nearest in composition to $3CaO.5Al_2O_3$, required the longest time for setting, while, as previously noted, $5CaO.3Al_2O_3$ sets so rapidly that it cannot be easily handled. The cements from burns Nos. 1 and 2, approaching closely the compostion $CaO.Al_2O_3$, have what would be considered a quick initial set but a normal final set. They lie between the $5CaO.3Al_2O_3$ and the $3CaO.5Al_2O_3$ in their setting properties. A comparison of the cements from burns Nos. 5 and 6 or from Nos. 4 and 7, which have closely the same silica content, shows that the time of set is dependent upon the lime —alumina content, the cement with the higher alumina content having the slower set.

In these cements the constituents other than the aluminates do not appear to materially affect any of the properties. The orthosilicate, when present in any quantities, was in the γ-form which does not hydrate and consequently does not set or acquire strength. The same is also true of the ternary compound $2CaO.Al_2O_3.SiO_2$. Consequently, these must be considered as non-hydraulic diluents.

Effect of the Addition of Plaster of Paris.—When the investigation was first started it was decided to add 3 per cent of plaster of paris to half of the material from each burn in order to regulate the time of set. Such additions to portland cement usually retard the set but when added to the cements in this

investigation it invariably accelerated the set to a marked degree. This is evident by a comparison of the following times of set (Table 3) of the plastered materials with the times of set previously shown (Table 2):

TABLE 3.

Effect of the Addition of Plaster of Paris on the Time of Set.

Burn No.	Initial set.				Final set.			
	Gilmore.		Vicat.		Gilmore.		Vicat.	
	Hours.	Minutes.	Hours.	Minutes.	Hours.	Minutes.	Hours.	Minutes
1	0	55	0	15	4	55	2	35
2	0	30	0	10	2	0	0	50
3	0	25	0	20	6	20	3	25
4	0	10	0	3	1	40	0	25
5	0	15	0	5	3	0	0	30
6		flash		flash				
7	0	35	0	20	4	30	2	30
8	1	5	0	20	4	0	2	45

While the acceleration is more pronounced in the case of the cements high in alumina, all of the work of the Bureau of Standards seems to show that, unless used in excessive amounts, plaster of paris when used alone accelerates the time of set. It would appear necessary that either lime, or a compound that can set lime free in the presence of water, must be present in a cement in order that plaster of paris may act as a retarder. This applies to portland cement as well as to the ones under discussion.

Strength Tests.—For determining the cementing value of these aluminates the following test pieces were prepared:

1. Neat tensile test pieces.

2. 1:3 standard sand mortar tensile test pieces.

3. 1:3 standard sand mortar 2-inch cube compression test pieces.

4. 6″ × 12″ cylindrical compression test pieces prepared from 1:1.5:4.5 and 1:3:9 gravel concretes.

These were broken at periods as shown in Tables 4, 5 and 6, the results given being the averages of determinations on 3 test pieces. All of the tension and the 2-inch compression specimens, with the exception of half of those broken at 28-day and 26-week periods, were stored under water. These were stored for one-quarter of the period in water and in air for the remainder of

TABLE 4.—TENSILE STRENGTHS OF 1 : 3 STANDARD MORTARS.

Pounds per square inch.

Tested at	24 Hours		7 Days		28 Days				90 Days		26 Weeks				1 Year	
Stored in	Water				Water	C.S.[1]	Water	C. S.	Water		Water	C. S.	Water	C. S.	Water	
	W. P.[3]	P.[2]	W. P.	P.	W. P.		P.		W. P.	P.	W. P.		P.		W. P.	P.
Burn No. 1	378	380	403	360	435	730	310	720	440	465	525	595	530	525	525	550
Burn No. 2	275	295	385	305	320	305	595	570	395	480	390	500	375	445	425	470
Burn No. 3	270	195	385	360	525	615	345	585	560	390	575	900	480	665	612	488
Burn No. 4	415	355	280	335	335	345	310	415	375	355	500	400	427	555	435	440
Burn No. 5	155	155	170	155	170	365	175	370	225	172	300	535	163	540	320	185
Burn No. 6	220	175	175	115	280	405	100	285	285	135	245	605	170	315	295	140
Burn No. 7	345	250	295	225	290	560	295	515	350	370	385	575	360	595	390	330
Burn No. 8	330	370	690	390	540	830	280	530	770	195	590	960	380	425	700	460

[1] C. S. = Stored for 1/4 of period in water and remainder of period in air.

[2] P. = Plaster added to the cement.

[3] W. P. = No plaster added to the cement.

TABLE 5.—COMPRESSIVE STRENGTHS OF 1 : 3 STANDARD MORTARS.

Pounds per square inch.

Tested at	24 Hours		7 Days		28 Days				90 Days		26 Weeks				1 Year	
Stored in	Water				Water	C. S.	Water	C. S.	Water		Water	C. S.	Water	C. S.	Water	
	W. P.[1]	P.	W. P.	P	W. P.		P.		W. P.	P.	W. P.		P.		W. P.	P
Burn No. 1	3570	2860	5945	2955	3765	6815	2790	4005	3945	3015	5330	6015	3860	4945	3045	2850
Burn No. 2	4260	3050	4760	4090	3945	7625	3535	5515	4735	4630	4570	5290	4850	5470	4430	3580
Burn No. 3	2240	1630	4940	2450	6475	8000	4655	2540	7180	3210	7760	11050	4630	7100	5315	3015
Burn No. 4	4410	3380	4880	2200	5285	6400	2965	5140	4565	2495	3470	3480	2270	4920	3200	2355
Burn No. 5	1035	1060	1400	1180	1820	2875	1160	2665	2070	1465	2900	3845	2200	3540	2410	1720
Burn No. 6	1340	1060	1260	940	1425	3130	2315	790	1680	925	1895	4345	1475	3055	2310	685
Burn No. 7	2165	1870	5140	1720	3930	7085	1415	3610	5205	2630	3605	6090	3080	5430	5225	2010
Burn No. 8	2860	2710	8610	4290	7845	10690	3680	7415	8260	4745	6380	8045	4605	7475	8945	4260

[1] See footnote Table 4.

TABLE 6.—COMPRESSIVE STRENGTHS OF 1 : 6 AND 1 : 21 GRAVEL CONCRETES.

Pounds per square inch.

Tested at	24 Hours			7 Days			28 Days			90 Days			26 Weeks			1 Year					
Proportions	1: 6	1:12	1:12 P.[1]	1:6	1:12	1:12 P.	1:6	1:12	1:12 P.	1:6	1:12	1:12 P.	1:6	1:12	1:12 P.	1:6	1: 6*	1:12	1:12*	1:12 P.	1:12 P.*
Burn No. 1**.	2825	..	..	3270	..	..	3310	..	..	4150	..	..	4180	..	..	3310	5590	..	..	..	..
Burn No. 2...	3000	..	1500	4150	..	1595	4740	..	1890	2480	..	1580	1760	..	1580	1760	2360	..	..	1530	2250
Burn No. 3...	Soft	..	..	2175	..	..	3680	..	..	3900	..	..	4525	..	..	4135	5660	..	..	..	..
Burn No. 4...	3145	880	1630	3570	1005	1435	3370	1000	1415	2930	875	1280	2565	800	1385	2965	3280	860	1275	1525	2480
Burn No. 5...	310	Soft	..	885	225	..	1250	365	..	1050	390	..	1270	550	..	1460	2110	570	870	..	..
Burn No. 6...	840	275	315	765	275	400	990	305	410	1260	400	700	1515	470	570	1440	2035	470	810	600	1055
Burn No. 7...	1475	455	375	4135	1405	675	4625	1500	645	4640	1600	800	4450	1580	600	4650	5300	1350	1815	655	1080
Burn No. 8...	2930	890	470	6010	2270	1480	7060	3415	1740	7050	3980	1760	7610	3910	1700	6720	8220	3930	4445	1470	2450

* All specimens in these columns were stored for the first 4 months in the damp closet and for the remainder of the period in the air of the laboratory. All other specimens were stored in the damp closet for the entire period of ageing.

** Cement used in making specimens from Burn No. 1, contained 3 per cent plaster.

[1] Footnote Table 4.

the period. The concrete specimens, with the exception of some of those tested at the end of a year, were stored in a damp closet. When it was noticed that some of the concrete specimens were showing a retrogression in strength after ninety days' storage in the damp closet, it was thought advisable to determine the effect of drying out on the strength of the specimens. A set of test pieces was therefore removed from the damp closet and stored in the air of the laboratory until the end of a year when they were broken. In practically all cases, similar test specimens were made of both the plastered and unplastered cements. Where this was not the case, it is shown in the tables.

Neat Cements.—The results of the tests of the neat specimens are not given. These were eliminated on account of the fact that at no period does there seem to be any relation between the strength developed by a cement as shown by a neat tension test piece and the strength which it may develop in a mortar or concrete. Such has also been found to be the case with portland cement and consequently the present revised specifications of both the Government and the American Society for Testing Materials for the latter no longer recognize or require a neat test piece. The following examples (Table 7) showing the strength of certain test pieces made from the cements containing no plaster, indicated in pounds per square inch at the end of one year, will illustrate this:

TABLE 7.

Burn No.	2	4	6	7	8
Neat tension	145	960	445	700	130
1:3 Mortar tension	425	435	295	390	700
1:3 Mortar compression	4430	3200	2310	5225	8945
1:6 Concrete compression	3220	2965	1440	4650	6720

A satisfactory explanation of this behavior is not at hand. Some have attempted to explain it by a nice distinction (?) between the "adhesive" and the "cohesive" strength developed by a cement, assuming that one with high "adhesive" strength gives a high testing mortar or concrete whereas one with a high "cohesive" strength gives a high testing neat specimen. However, it is rather difficult to appreciate such a distinction.

The examination of the data of these tables shows as the

most striking feature the high strength at early periods of all of the mortars and concretes with the exception of those made from cements Nos. 3 and 5. At the present time, Standard Specifications for portland cement have no requirements for strength specimens other than the tensile mortar briquettes. These require that the 1:3 Standard Ottawa sand briquette should have a strength of at least 200 pounds per square inch at the end of 7 days and at least 300 pounds per square inch at the end of 28 days. In Table 4 it is shown that the materials from 4 of the 8 burns develop a greater strength in 24 hours than is required of portland cement in 28 days. The strengths developed by the other kinds of test pieces used are relatively high when compared with the same kind of specimens made from portland cement. Generally, cements Nos. 1, 2, 4, 7 and 8 develop as great a strength in any form of test piece in 24 hours as portland cement will develop in 28 days.

Effect of Plaster.—Those specimens made from the cements to which plaster had been added and which had been stored in water continuously did not usually develop as high strength as the specimens made from the cements from which the plaster had been omitted. This is more pronounced in the case of the compressive than in the tensile specimens.

Effect of Storage.—The storing of the specimens in the air of the laboratory—after storage in water for about one-quarter of the entire period—produced very marked increases in strength over that developed by the specimens stored in water for the entire period. A 50 per cent increase was common and in some cases it exceeded 100 per cent. In passing, it might be mentioned that German specifications for portland cement require that the 28-day test pieces be stored for the first day in the damp closet, then for 6 days under water and the remainder of the time in the air of the laboratory. It is claimed that such storage follows more closely the manner in which mortar or concrete would be handled in practice. However, seasonal or even daily changes in the atmospheric humidity render such storage in the air open to serious criticism. These changes materially reduce the possibility of reproducing results at different times or places from the same cement.

Generally, the concrete specimens showed a decrease in strength with age when stored in the damp closet. This is not surprising when the nature of the hydration of these cements is remembered. This consists in the splitting off of the alumina from the aluminates and its separation as gelatinous hydrated alumina and the formation of hydrated tricalcium aluminate. The latter, until late periods when it tends to change to a crystalline form, is also gelatinous. All of these gelatinous or colloidal products of hydration which form the cementing materials act as any other glue. In the presence of too great amounts of moisture the latter is absorbed and in the presence of small amounts it is given up. Whether water is absorbed or given up by the colloid depends upon the amounts in the colloid and in the gaseous phase. When cements, such as those under consideration, form large amounts of colloid, it follows that the changes caused by moisture will be very pronounced. With the taking up of large amounts of moisture the strength of the specimens will be materially reduced. When the colloid dries out—provided the drying is not carried too far—there is an increase in strength. Just as the moisture content of the atmosphere does not materially affect the strength of an organic glue (such as fish or bone glue) so also it does not decidedly change the strength of mineral glue unless it contains too great amounts of water.

There was not a sufficiently large number of burns in the series to permit of much generalization in regard to the relations between mineral composition or constitution and strength. It is quite evident, however, that the cements with the higher alumina contents develop the higher strengths. The strength is decreased by increasing the silica content—especially if the silica replaces the alumina. However, when silica must be introduced, much better results are obtained by keeping the alumina content constant and replacing lime. The one essential in the composition is to keep the content of alumina such that the composition will approach that of $3CaO.5Al_2O_3$.

High Strength Cements.—Some of the strengths developed by the cements were so high that they are worthy of special citation. Cement No. 8 gave a 1 : 3 mortar which developed a tensile strength of 770 pounds per square inch at ninety days and 960

pounds per square inch at twenty-six weeks (by the combined storage), and a compressive strength of 8,610 pounds at 7 days and 10,690 pounds at twenty-eight days (by the combined storage) and a 1:6 concrete with a strength of 6,010 pounds at 7 days and 8,220 pounds at one year (by the combined storage). Cement from burn No. 4 gave a 1:6 concrete having a strength of 3,145 pounds in twenty-four hours. The average twenty-four-hour strengths of the 1:6 concretes of cements from burns Nos. 1, 2, 4 and 8 was 3,000 pounds. It should be borne in mind that the above figures are the averages of determinations on 3 test pieces and consequently some individual test pieces gave higher strengths.

CONCLUSION.

It appears from this investigation that it is possible to make, by a method and equipment differing in no manner from that used in making portland cement, cements giving in twenty-four hours strengths as high as those usually developed by portland cements in twenty-eight days—either as a mortar or concrete. This quick-hardening cement is not quick-setting. It differs from portland cement in being a calcium aluminate high in alumina (preferably 55 to 75 per cent). The presence of silica or iron oxide is not desirable but they may be present in amounts up to 15 per cent—provided they replace the lime and not the alumina.

The commercial possibilities of such a cement are not very promising on account of the lack of a widely distributed supply of alumina. While the actual cost of manufacture would not exceed that of portland cement, the cost of the alumina alone would so raise the ultimate cost of the cement that the use of the finished product for any except very special purposes would be precluded.

This opportunity is taken to acknowledge the valuable assistance rendered by Messrs. Klein, Peck and Tucker at various times while the investigation was under way.

NOTE ON CERTAIN CHARACTERISTICS OF PORCELAIN.[1]

By A. V. Bleininger, Pittsburgh, Pa.

Porcelains vary widely in their physical properties such as modulus of elasticity, coefficient of thermal expansion, heat conductivity and electrical resistance at different temperatures. It is not uncommon for instance, to find differences in the modulus of elasticity as far apart as 6,600,000 and 1,200,000. Again, the coefficient of thermal expansion is subject to decided variations for different porcelains as well as for the same material at different temperatures. With reference to the electrical conductivity, the values observed for different temperatures are subject to equally wide variations.

These facts are not at all surprising and are explained by the various stages of development represented by different porcelains. In practically all of them we have conditions far removed from such equilibria as we find in glasses depending upon the composition, the fineness of grinding and intimacy of blending, the rate and the ultimate temperature of firing, and finally the rate of cooling. As a result, the amounts of undissolved quartz or cristobalite, of glassy matrix, of undecomposed clay and of sillimanite fluctuate within wide variations. It is obviously of great importance whether the quartz content is high or low, whether it is comparatively coarse or fine, whether the percentage of feldspar is small or large or whether additional or different fluxes are introduced, and last but not least, what the temperature treatment has been. It is only through more refined and exact measurements that we may obtain a clear notion of the relation between the physical properties of porcelain and the several factors governing them.

In the low-fired porcelains—those fired to about cone 10—it is evident that the amount of undissolved quartz is comparatively large and that of sillimanite small. It is to be expected, therefore,

[1] By permission of the Director, Bureau of Standards.

that this product is subject, upon heating, to the changes in specific volume coincident with the transformations of quartz and cristobalite. It is not unlikely that some of this type of porcelain, when made into heavy pieces, is in a state of stress—due to its heterogeneous structure which has not been modified by high temperature treatment. It is to be expected, on the other hand, that the structure would gradually approach a more balanced, because more homogeneous, state, as higher firing temperatures, which cause far-reaching solution of the quartz and practically complete dissociation of the clay substance into sillimanite, are employed. The development of the latter mineral is desirable owing to its stability, being subject to no transformation changes, its density, 3.031, and its low coefficient of thermal expansion.

The undesirable characteristics of quartz in heavy porcelains are well understood by the manufacturers of sanitary ware who avoid its introduction as much as possible and insist upon the use of French flint—a partially amorphous modification of silica which inverts into cristobalite much more quickly and probably is also dissolved more readily by the fused feldspar. It is not unlikely that the objectionable property of "dunting" and its minor manifestations do not appear until the amount of quartz exceeds a certain value which has not yet been established. In the case of electrical porcelain subject to high tensions, it is more than likely that the permissible content of free quartz remaining in the porcelain is very much lower if maximum stability is desired. In advocating a high clay content for chemical porcelain subject to severe duty, E. T. Montgomery, therefore,[1] proceeds on sound principles and his conclusions deserve careful attention.

In the Pittsburgh laboratory of the Bureau of Standards a large series of porcelains have been made in which quartz has been replaced both by clay and by synthetic sillimanite. In both cases porcelains of excellent stability have been obtained as shown by the resistance of the bodies to sudden heating and cooling. Particularly was this the case by the use of the sillimanite which was prepared by grinding together 258 parts of kaolin, 102 of anhydrous alumina and 7.2 of boric acid, and heating the mix-

[1] *Trans. Am. Ceram. Soc.*, **18**, 88–92 (1916).

ture to the softening temperature of cone 20. The calcined material consisted largely of sillimanite with a small amount of uncombined alumina. It was again ground and introduced in the body, replacing the flint. As a type, these porcelains, expecially that in which 40 per cent of sillimanite calcine was used together with 40 per cent of clay and 20 per cent of flux, when fired to cone 16, not only showed excellent resistance to sudden heating and cooling but also high mechanical strength. At the same time the sillimanite increased the firing range of feldspar porcelain decidedly. By raising the amount of sillimanite to even larger proportions, porcelains of still more marked stability could be produced. Similar results were obtained through the introduction of other minerals not subject to molecular transformations, such as fused alumina, zirconium oxide, etc. The thermal expansion is decreased with the replacement of quartz by such constituents. The body obtained with the use of the zirconia seemed to be especially desirable for purposes where high mechanical strength was necessary.

It has been known for some time that the dielectric strength of porcelains is greatly reduced upon heating. Messrs. Henderson and Weimer[1] found that when heated from 24° to 275° C, a body fired to cone 9 showed a reduction in the puncturing voltage down to $^1/_{30}$ of the initial value. The same experience holds true also for the electrical resistance of vitrified bodies. In fact, the conductivity of such materials increases very rapidly with temperature—according to the law of compound interest at the rate of about 2 per cent per degree C. That this introduces an important factor in the case of porcelains exposed to higher temperatures, such as spark plugs, high tension insulators used in Cottrell process installations, etc., is obvious.

In order to secure information concerning the effect of composition upon these phenomena, a large number of porcelains were made and tested. The specimen used for this purpose was a cup of 60 mm. outside diameter, 65 mm. height and having a thickness of wall of 2.5 mm. The cup was placed in a suitable electrically heated furnace. Electrical contact was provided by

[1] *Trans. Am. Ceram. Soc.*, **13**, 469–475 (1911); also Weimer and Dunn, *Ibid.*, **14**, 280–292 (1912).

the use of molten solder on the inside of the cup and its immersion in a shallow metal bath on the outside.

Alternating current, 60 cycle, of 500 volts, was employed—since direct current gave rise to disturbing polarizing effects. The current passing through the porcelain was measured by means of a very sensitive milliammeter or a dynamometer wattmeter. The temperature was determined by means of two insulated thermocouples immersed in the molten solder of the inside of the cup.

The results of the resistance measurements were plotted as the $\log_{10}$ R against the temperature, in degrees C. The plots were approximately straight lines expressed by the relations

$$\log_{10} R = a - bt,$$

where R = resistance of the specimen, in ohms,

t = temperature in degrees C, and a and b are constants.

By computing a resistivity factor, based on the dimensions of the cup, it was possible to calculate the resistance per cubic centimeter of the porcelain. The criterion used in comparing the merits of each body was the temperature *Te* at which the material has the definite resistance of one megohm per centimeter cube.

The electrical measurements and computations were made in the electrical laboratory of the Bureau of Standards at Washington.

A characteristic curve for a feldspar porcelain is shown in the diagram of Fig. 1, for which the value *Te* = 335° C. Upon studying the resistance curves of a number of porcelains it was soon apparent that the feldspar was the important factor in lowering the electrical resistance at these temperatures. Invariably, the higher the feldspar content the lower was the resistance and the value *Te*. By eliminating the feldspar and carrying the maturing temperature to a high point, say cones 18–20, bodies of good resistance at the temperatures involved were obtained. The same result was reached when the feldspar was replaced by synthetic silicates containing beryllium oxide, magnesia or other alkaline earths. Through the elimination of the feldspar it was found possible to reach a *Te* value as high as 800° C, which is quite satisfactory when one considers that fused quartz gave the result of 880° C.

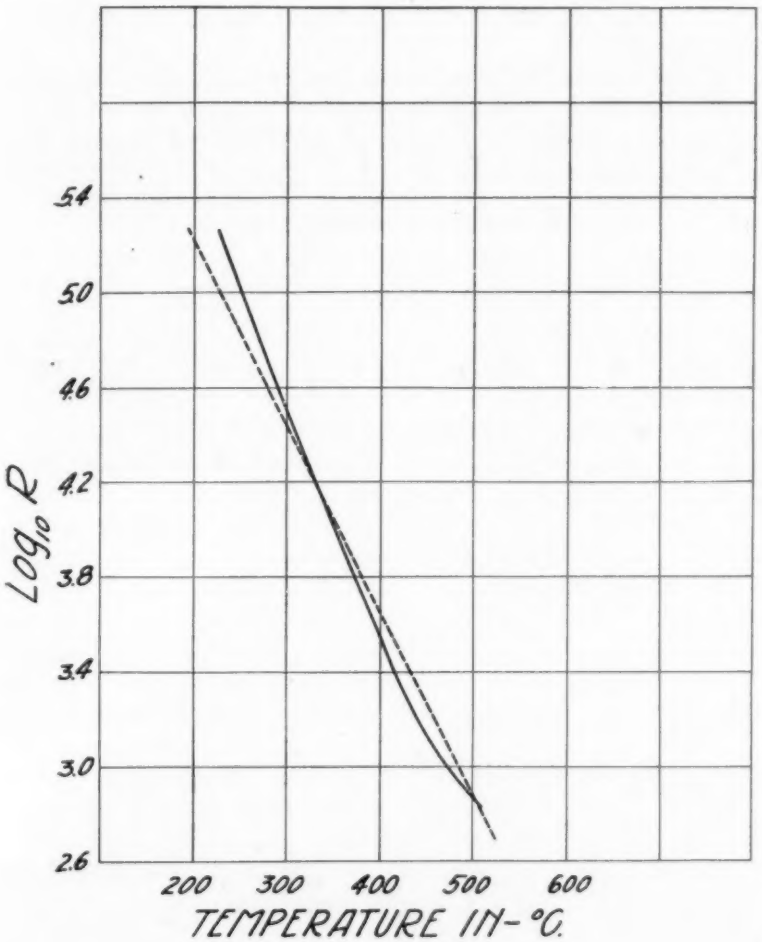

FIG. 1.

It also appeared that with higher feldspar content the polarization phenomena became more prominent, indicating clearly that this constituent of porcelain plays a rôle of an electrolyte. It is evident, therefore, that for conditions where a high tension porcelain insulator is exposed to elevated temperatures it is neces-

sary to reduce the content of the feldspar and to replace it by some other flux.

For porcelains intended to be used under severe electrical and heat conditions, it would appear desirable, therefore, to eliminate both the quartz and the feldspar as constituents of the body in the manner suggested above.

ENAMELS FOR CAST IRON.[1]

By Homer F. Staley, Washington, D. C.

I. TIN ENAMEL COMPOSITIONS.

Basis of Classification.

The tin enamel compositions for cast iron in common use have, for the most part, been developed in factory practice through long years of patient cut-and-try experiments by men who had little knowledge of chemistry and less of physics to guide them. In recent years a few ceramic engineers have entered this field and have materially reduced the cost of the enamels in use. This reduction in cost, however, has consisted mainly in substituting cheap forms of chemicals for more expensive forms and the elimination of a few expensive ingredients of little value. The general types of enamels had been too thoroughly worked out in practice to permit any radical innovations. The fact that these types have stood the test of time and are really a "survival of the fittest" is in itself proof that they must conform, at least roughly, to the laws of physics and chemistry applicable to enamel compositions.

Many factors determine the availability of an enamel, such as fusibility, luster, coefficient of expansion, strength, elasticity, color, and hardness and resistance to chemical agents. Enamel compositions might be classified according to the relation of compositions to any one of these factors, but the most obvious relation is that of composition to luster, as dependent on the ability of the enamel to remain glassy and not devitrify during working and cooling. Of course, all of the other factors have a modifying effect in determining the actual compositions used. In fact, any enamel composition is a compromise.

As stated under the discussion of luster,[2] boric oxide and lead oxide are the only fluxing oxides that can be present in enamels

[1] By permission of the Director, Bureau of Standards.

[2] This Journal, 1, Sept. (1918).

in large amounts without causing devitrification. The amount of the other fluxing oxides that may be added without causing devitrification is so small that it is practically impossible to make a satisfactory enamel for cast iron unless the sum of these two oxides is above a certain minimum. Boric oxide is always used, and tin-bearing enamel compositions fall into three general types: (1) Leadless enamels, (2) low lead enamels, (3) high lead enamels (Table 1). Of course it is understood that the following compositions (Table 1) are for powdered enamels to be applied to cast iron:

The Leadless Type.—The leadless type of enamel has been developed in Germany. It is characterized by a very high boric oxide content. Since the enamel is so high in boric oxide, it would have a very low coefficient of expansion and would therefore tend to chip, other factors, such as strength and elasticity, being equal, if this were not corrected in the rest of the composition. Therefore, the German enamels high in boric oxide are high in sodium oxide and cryolite, both of which have a very decided tendency to raise the coefficient of expansion of enamels. Since boric oxide has a favorable effect on the strength and elasticity of enamels, the unfavorable effect of a large amount of sodium oxide on these properties is counter-balanced. On account of the solvent action of glasses high in sodium oxide on tin oxide, the amount of the latter substance is high, compared to American practice.

Enamel 1 (Table 1) published by Dr. Julius Grünwald[1] who has written extensively on German enameling practice, is a formula of this type. Clay is seldom used in making enamel melts in America, and the amount of tin oxide in Grünwald's formula would be considered excessive. A formula such as Enamel 2 conforms more nearly to American ideas of what a leadless enamel high in boric oxide should be.[2]

The Low Lead Type.—Since lead oxide is present in considerable amounts in the low lead type of composition, the boric oxide can be lower than in the previous type without danger of

[1] *Stahl u. Eisen*, **30**, 1204.

[2] H. F. Staley and G. P. Fisher, *Trans. Am. Ceram. Soc.*, **15**, 626 (1913).

devitrification taking place. The lead oxide generally runs under 10 per cent and the boric oxide over 8 per cent. In American practice, considerable zinc oxide is generally used in this type of enamel. Enamel 3 is an old formula for this type of enamel and Enamel 4 is a modern derivative of the same formula.

The High Lead Type.—In the high lead type of enamel the lead oxide runs from 16 to 25 per cent of the melted weight of the enamel. Since the lead oxide is so high the boric oxide can be low (around 6 per cent of the melted weight), as in Enamel 5, without danger of devitrification. However, on account of considerations of strength and elasticity, the boric oxide is often kept as high as 8 per cent in high lead enamels as in Enamels 6 and 7. The amounts of the other fluxing oxides vary widely, but any one seldom exceeds 10 per cent. This is the type of powdered enamel for cast iron most commonly used in this country and many formulas might be given, but Enamels 5, 6 and 7 (Table 1) are typical.

TABLE 1.—TIN ENAMEL FORMULAS.
Raw batch for 1000 pounds melted.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7
Potash feldspar	340	410	380	400	380	380	380
Clay	55	..	..	..	..	..	..
Sodium nitrate	5.5	30	..	30	25	30	30
Soda ash	21	..	30	90	50	30	30
Borax	555	240	225	225	165	215	215
Cryolite	110	120	10	40	..	30	..
Fluorspar	5.5	..	85	85	120	50	50
Ammonium carbonate	8	..	1	..	..	..	..
Magnesium carbonate	5.5	..	..	..	..	..	..
Tin oxide	188.6	83	92	94	85	90	90
Boric acid	..	220	..	..	..	..	..
Zinc oxide	..	125	108	108	60	105	50
Quartz	..	..	15	..	..	..	..
Potassium nitrate	..	..	60	..	..	..	..
Potassium carbonate	..	..	30	..	..	..	..
Red lead	..	..	82	94	175	168	255
Sodium silico fluoride	..	..	40	..	..	..	..
Manganese dioxide	..	..	1	..	..	..	..
Arsenic oxide	..	..	6	..	..	..	..
Barium carbonate	..	....	..	..	75	50	50
	1294.1	1228	1165	1166	1135	1148	1150

TIN ENAMELS.

Percentage Composition.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Silica	24.46	26.5	26.08	25.88	24.58	24.58	24.58
Alumina	8.44	7.5	7.00	7.36	7.00	7.00	7.00
Potassium oxide	5.66	7.0	11.22	6.76	6.42	6.42	6.42
Sodium oxide	10.41	5.0	5.38	9.95	6.50	6.31	6.31
Boric oxide	20.33	21.2	8.23	8.23	6.04	7.87	7.87
Aluminium fluoride	4.40	4.8	0.40	1.60	...	1.20	..
Sodium fluoride	6.60	7.2	2.36	2.40	...	1.80	..
Magnesium oxide	0.26	...	..	..	...	..	..
Tin oxide	18.86	8.3	9.20	9.40	8.50	9.00	9.00
Zinc oxide	...	12.5	10.80	10.80	6.00	10.50	5.00
Lead oxide	...	...	8.00	9.20	17.10	16.50	25.00
Silicon fluoride	...	...	2.24	..	...	..	..
Calcium fluoride	0.55	...	8.50	8.50	12.00	5.00	5.00
Manganese oxide	...	...	0.10	..	...	..	..
Arsenic oxide	...	...	0.60	..	...	..	..
Barium oxide	...	...	..	..	5.83	3.88	3.88
	99.97	100.0	100.00	100.08	99.97	100.06	100.06

TIN ENAMELS.

Empirical Chemical Formulas.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
K_2O	0.188	0.187	0.230	0.130	0.130	0.140	0.153
Na_2O	0.773	0.423	0.222	0.345	0.201	0.294	0.230
CaO	0.021	...	0.212	0.200	0.295	0.132	0.145
MgO	0.018	...	...	...	...	...	...
BaO	...	...	...	...	0.073	0.052	0.059
ZnO	...	0.390	0.258	0.244	0.142	0.269	0.140
PbO	...	...	0.076	0.081	0.159	0.153	0.273
MnO	...	...	0.002	...	...	...	...
Al_2O_3	0.332	0.260	0.138	0.150	0.132	0.157	0.156
SiO_2	1.255	1.118	0.882	0.790	0.785	0.847	0.920
B_2O_3	0.890	0.766	0.229	0.216	0.155	0.231	0.253
SnO_2	0.383	0.140	0.118	0.114	0.107	0.124	0.135
F_2	0.519	0.436	0.356	0.266	0.295	0.218	0.144

II ANTIMONY ENAMEL COMPOSITIONS.[1]

Sodium Metantimonate Enamel Compositions.

Sodium metantimonate has been employed extensively in this country during late years as an opacifying agent for enamels

[1] For detailed treatment of color phenomena, etc., see Staley, *Trans. Am. Ceram. Soc.*, **17**, 173–189 (1915).

for cast iron. The compositions used may be divided into three types: the leadless, the low lead, and the medium lead (Table 2).

The Leadless Type.—In Germany leadless enamels in which sodium metantimonate is the opacifier have been derived from the leadless tin enamels, similar to Enamel 1 (Table 1), very high in boric oxide and containing only one or two other fluxes. In this country, however, leadless enamels containing sodium metantimonate have been derived from the complicated formulas in use for tin enamels, by the substitution of other fluxes for lead oxide. This has resulted in complicated formulas, rather high in boric oxide and generally high in zinc oxide. Boric oxide is increased as lead oxide is decreased because, when used in large amounts, it not only does not itself crystallize but it makes the enamel more viscous and thus prevents the crystallization of other compounds that may have been used to partially replace lead oxide.

The zinc oxide is increased as the lead oxide is decreased in order to maintain the strength and elasticity of the enamel. By using a complicated formula the amount of each of the other fluxing oxides is kept low, so that tendency for their compounds to crystallize and cause dull luster is lessened. Enamel 8 (Table 2) is a typical composition.

The Low Lead Type.—The low lead type of composition contains 3 to 5 per cent of lead oxide; the boric oxide and zinc oxides are usually a little lower than in the leadless type. The amount of each of the other fluxing oxides is kept low. Enamel 9 is a typical example. In this the percentage of sodium oxide is approaching the danger limit as far as luster of the enamel is concerned. Its use would be safer if 50 pounds of borax were substituted for the 45 pounds of soda ash. This would give boric oxide and sodium oxide contents like those in Enamel 8.

The Medium Lead Type.—In the medium lead type of composition, the lead oxide runs between 5 and 12 per cent. The boric oxide is slightly lower than in the previous type, but still higher than in high lead tin enamels, and the percentage of each

of the other fluxing oxides is kept low. Enamels 10 and 11 are typical compositions. It will be noted that in Enamel 11 no calcium carbonate is used, but that a larger amount of fluorspar is used than in the other compositions. Thus the calcium content is maintained at the proper point to give good color and opacity.

Oxide of Antimony Enamel Compositions.

The essential difference between sodium metantimonate enamel compositions and those in which oxide of antimony is used as the chief opacifier is that the latter contain much larger amounts of sodium nitrate. Corresponding reduction is made in other sodium compounds so that the total sodium oxide content remains about the same. This larger nitrate content may mean that the oxide of antimony is converted into sodium metantimonate ($Na_2O.Sb_2O_5$) or simply into antimony pentoxide (Sb_2O_5). Incidentally the oxide of antimony enamels which the writer has found in actual use in factories contain considerable cryolite, and therefore the percentage amount of oxide of antimony can be lower than in the case of sodium antimonate compositions containing little or no cryolite.

TABLE 2.—ANTIMONY ENAMEL FORMULAS.

Raw batch for 1000 pounds melted.

	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
Potash feldspar	390	390	390	375	410	410	410	400
Sodium nitrate	35	35	35	25	70	70	90	75
Borax	350	300	250	275	350	300	240	230
Barium carbonate	80	80	70	100	80	75	80	80
Zinc oxide	140	110	85	70	140	100	100	92
Calcium carbonate	30	30	30	..	30	30	30	25
Fluorspar	73	73	..	100	60	73	45	55
Sodium antimonate	120	120	120	110	..	..	..	..
Soda ash	..	45	55	25	..	25	30	20
Red lead	..	31	85	102	..	46	82	117
Calcium fluoride	..	..	73	..	..	..	..	..
Cryolite	..	..	..	..	40	40	45	45
Antimony oxide	..	..	..	..	60	60	64	58
	1218	1214	1193	1182	1240	1229	1216	1197

ANTIMONY ENAMELS.

Calculated percentage composition, melted.

	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
Silica	25.23	25.23	25.23	24.26	26.53	26.53	26.53	25.88
Alumina	7.18	7.18	7.18	6.90	7.54	7.54	7.54	7.36
Potassium oxide	6.59	6.59	6.59	6.34	6.93	6.93	6.93	6.76
Sodium oxide	8.94	10.75	10.52	8.57	8.22	8.86	8.91	7.62
Boric oxide	12.81	11.00	9.15	10.06	12.81	11.00	8.78	8.42
Barium oxide	6.21	6.21	5.44	7.77	6.20	5.83	6.21	6.21
Zinc oxide	14.00	11.00	8.50	7.00	14.00	10.00	10.00	9.20
Calcium oxide	1.68	1.68	1.68	..	1.68	1.68	1.68	1.40
Antimony oxide	10.00	10.00	10.00	9.24	6.00	6.00	6.40	5.80
Lead oxide	...	3.00	8.40	10.00	...	4.50	8.00	11.50
Calcium fluoride	7.30	7.30	7.30	10.00	6.00	7.30	4.50	5.50
Sodium fluoride	...	...	...	..	2.40	2.40	2.70	2.70
Aluminium fluoride	...	...	...	..	1.60	1.60	1.80	1.80
	99.94	99.94	99.99	100.14	99.91	100.17	99.98	100.15

ANTIMONY ENAMELS.

Empirical chemical formulas.

	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
K_2O	0.127	0.125	0.128	0.129	0.132	0.133	0.135	0.133
Na_2O	0.263	0.311	0.310	0.267	0.288	0.310	0.328	0.293
CaO	0.225	0.223	0.228	0.246	0.194	0.227	0.163	0.180
BaO	0.072	0.072	0.066	0.100	0.073	0.069	0.074	0.075
ZnO	0.313	0.244	0.193	0.166	0.313	0.224	0.228	0.214
PbO	...	0.025	0.075	0.092	...	0.037	0.072	0.105
Al_2O_3	0.129	0.127	0.130	0.131	0.150	0.151	0.157	0.158
SiO_2	0.761	0.754	0.777	0.777	0.801	0.803	0.818	0.808
B_2O_3	0.332	0.282	0.240	0.277	0.332	0.287	0.231	0.225
Sb_2O_3	0.063	0.063	0.064	0.062	0.038	0.038	0.041	0.038
F_2	0.170	0.169	0.173	0.246	0.238	0.269	0.188	0.216

These compositions can be divided into the same three types as sodium antimonate enamels, the characteristics of each type being practically the same as before. Enamel 12 (Table 2) is typical of the leadless type, Enamel 13 of the low lead type and Enamels 14 and 15 of the medium lead type.[2]

[2] Compare R. E. Brown, *Trans. Am. Ceram. Soc.*, **14**, 740–755; H. F. Staley, *Ibid.*, **17**, 173–189.

A METHOD FOR THE DETERMINATION OF AIR IN PLASTIC CLAY.

By H. Spurrier.

Although almost universally used in the pottery industry in the preparation of plastic clay bodies, the potters pug-mill is not an efficient piece of apparatus. Though a certain amount of pugging is necessary, an over-liberal treatment may injure an otherwise good body by the introduction of an excessive amount of air. In experimenting with pug-mills it was found desirable to determine the actual air content of various samples of clay. In making this determination it was evident that a method which actually separated and measured the contained air would be the most likely to give satisfaction. With this in view, some experiments were made in order to determine the feasibility of disintegrating samples of pugged clay in boiling water. So encouraging were the results that it was determined to extend the preliminary work so as to include the measurement of the contained air in extruded samples, thrown samples, and also in sections cut from clay filter press leaves. These simple experiments afforded some quite unexpected information in regard to the structure of the blanks examined.

The manner in which a piece of clay slakes down in water indicates at once the method of its formation. In an extruded blank, made on a special machine, we observed that the separation of the clay particles took place along longitudinal lines—indicating that the air cavities lie along parallel planes (Fig. 1, *a*). Thrown blanks exhibited very plainly the spiral striae formed in the process of throwing (Fig. 1, *b*). A section cut from a filter-press leaf did not slake or disintegrate in boiling water but remained indefinitely in the water without slaking down (Fig. 1, *c*). This latter case shows clearly that it is the disruptive effect of the gas vesicles, expanding under increasing temperature, that causes the clay to slake down, thus allowing the gases to escape.

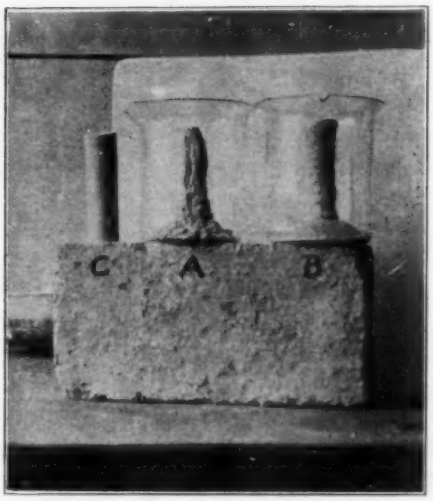

FIG. 1.—Showing the behavior of clay blanks in slaking down in water.

It became evident that if the air separation could be made quantitatively it might be made the basis of a clean-cut determination. Accordingly, an apparatus was assembled to accomplish this end. It was ascertained that kerosene did not have any tendency to slake the clay or in any way disturb it, neither did it dissolve the air.

A heavy 600 cc. flask (Fig. 2, *a*) was fitted with a two-hole rubber stopper. The larger hole, being evenly cupped at the smaller end of the stopper, was fitted with a 7 mm. glass tube just reaching to the bottom of the cup. The smaller hole was fitted with a right-angle bend, one limb extending to the bottom of the flask, the other terminating at a conveniently short distance from the bend; this tube was susceptible of connection with either a kerosene reservoir or a supply of boiling water (Fig. 2, *b*). The larger tube was surmounted by a two-hole rubber stopper entering the enlargement of the measuring tube; the other hole of the stopper was fitted with a glass tube that effected connection with and reached to the bottom of a 2500 cc. bottle (Fig. 2, *c*) containing

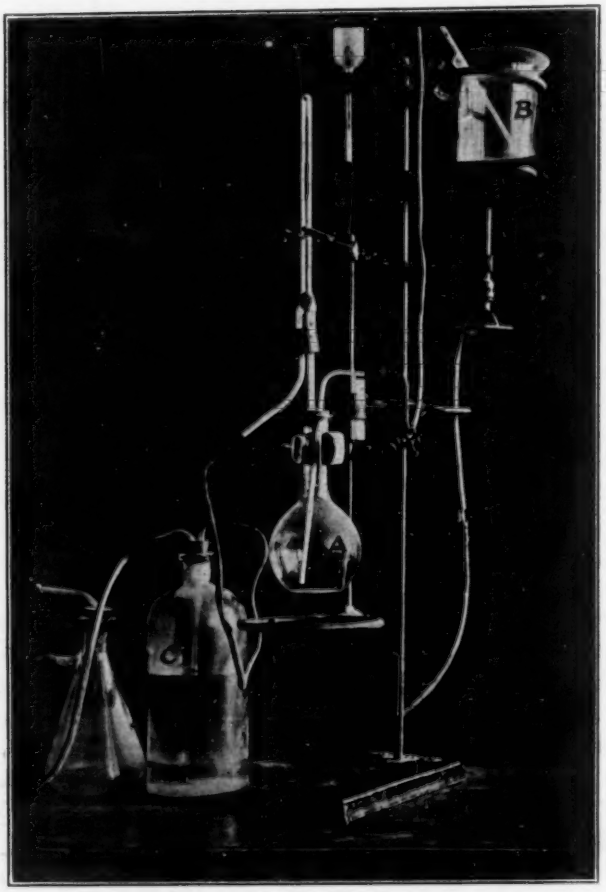

FIG. 2.—Apparatus used in the determination of the air content in clays.

500 cc. of kerosene and connected with a jet-vacuum pump. The whole was mounted on a universal stand as clearly shown. The determination is made as follows:

The duly measured (weighed if desired) blank is placed in the flask filled with kerosene which is then tightly corked. Kerosene is allowed to flow from the elevated reservoir until it overflows

into the 2500 cc. suction bottle. The whole is then turned through an angle of about 100 degrees and more kerosene run in so as to fill the measuring tube and completely expel every bubble of air. The apparatus is then placed in erect position and clamped and the kerosene tube connected with the boiling water in the elevated liter beaker in such a manner that no air enters the tube. This manipulation requires no more dexterity than is called for in an ordinary gas analysis. The boiling water is now run into the flask, completely displacing the kerosene—the excess water running out of the system into the suction bottle—and the screw-cock closed. The disintegration of the clay commences at once with the consequent liberation of the contained gases, which rise to the top of the measuring tube—duly calibrated in 0.1 cc. divisions for a space of 25 cc. and reading from above downward. A water bath is supported around the flask (Fig. 2, *a*) which is occasionally tapped with the finger tips to effect necessary agitation. The vacuum pump is set in operation causing considerable dilatation of the gas bubbles and duly facilitating their collection in the measuring tube. After about fifteen minutes, the vacuum is broken and upon equalizing the pressure by using the vacuum bottle as a leveling bottle, as customarily practiced in gas analysis, the volume of air is read and the temperature taken. The data is now in hand for calculating the volume of gas to normal temperature and pressure or any other basis preferred. The following results illustrate the application of the method:

A sample of air-free filter press clay was passed through a pug-mill and the air content determined to be 9.61 per cent by volume of the clay sample—calculated at room temperature, no correction for the barometer being necessary. On passing this clay through another pug having well-set blades the air content was found to be 9.88 per cent by volume.

Another sample was passed five times through a special pug after which the air content was found to be 13.18 per cent by volume.

The method lends itself admirably to the determination of the proper blade setting of pug-mills and the determination of the soundness of pugged clay insofar as air content is concerned.

JEFFERY DEWITT CO.,
DETROIT, MICH.

DISCUSSION.

PROF. BINNS: I have recently had occasion to take up again the question of using the French rolling table instead of the pug-mill in the preparation of potters clay. There is no question in my mind but that the French rolling table is the ideal machine for preparing clay and its use would overcome a great many of the difficulties arising from the air in the plastic body. It does not, however, prepare the clay as rapidly as the pug-mill and this has been one of the objections to its use.

MR. GORTON: I would like to ask if a determination of the air content was made upon clay which had been wedged by hand?

MR. SPURRIER: No, we do not use the wedging process in our plant at present. At one time we used the wedging process in the preparation of the clay for a special purpose. In this case we noticed that the lamination planes in the blanks were parallel to the axis of throwing and that the distribution of the air was very uneven. It has been our experience that wedging is not a satisfactory process for the preparation of the clay blanks.

MR. BARRINGER: This question of occluded air is, I think, particularly important in Mr. Spurrier's line, which I understand is the manufacture of spark plugs, where the elimination of the air is necessary to the production of the maximum mechanical and dielectric strength. It is not clear to me, however, why it is equally important to eliminate the air from other ceramic wares. I can sympathize with manufacturers of white ware, etc., who claim that the French rolling table process is too slow. Why is not the pug-mill satisfactory for the preparation of the clay for such wares? Would it not be possible to operate a pug-mill under low air pressure and thus gain the desired capacity together with the complete or almost complete elimination of the air?

MR. LOVEJOY: There is one device on the market and a patent pending on another which is designed to do that which Mr. Barringer suggests; that is, to shred the clay to release the air and remove the latter by suction. The inventor who is working on this device claims that laminations and the faulty dry-

ing which results from laminations are largely due to the included air.

MR. SPURRIER: In regard to the removal of the air by the employment of a vacuum, I do not believe it possible to get very good results. When a piece of clay is subjected to a decreased pressure, which we improperly call a vacuum, the air vesicles expand, it is true, but they are not removed. The air vesicle may be dilated but still remains in the clay. It is very interesting to note that if a piece of clay is placed in a bottle in kerosene and subjected to alternating increased and reduced pressure, it will behave like a piece of rubber. The air vesicle is not removed but increases and decreases in size with the variations in pressure.

MR. BROWN: Would it be possible to remove the air from a clay slip in that way?

MR. SPURRIER: Yes, that is being done. If you subject a slip in a bottle to reduced pressure, it will increase in volume, and if you tap the bottle with the knuckles, a leaden sound is given forth, indicating a lack of continuity. If the evacuation has continued long enough and all of the air is removed, the bottle will ring when tapped. The removal of the air from a heavy slip by evacuation is not practicable.

MR. BARRINGER: The statement confirms my opinion that air may be worked from a clay by some such method as kneading but is not readily removed by reducing the outside air pressure. As to pugging under reduced air pressure, I believe that this would involve considerable mechanical difficulty in the operation and maintenance of the apparatus.

NOTES ON SAGGER CLAYS AND MIXTURES.

By G. H. Brown, New Brunswick, N. J.

Introduction.

The sagger problem, although an old one, does not appear any nearer its solution than it was several years ago. The sagger losses in our potteries and other ceramic industries is a serious one and the life of the saggers is an important item in the profit and loss columns in most of the plants. It is true that there is considerable variation in the length of life of the saggers used in the different plants, but there appears to be no generally accepted practice particularly as to the kinds of clays used in the sagger mixtures. Frequently, a change in the composition of the sagger mixture is necessitated by inability to secure the clays formerly used and the consequent substitution of new and untried materials in the sagger batches.

In a great many plants, the composition of the sagger mixture is governed for the most part by the cost of the clays—the quality of the clays and their suitability for this purpose being secondary to the price per ton. However, very often, a so-called low-grade or cheap clay will produce a sagger having longer life than some of the so-called high-grade clays sold at fancy prices.

Character of Sagger Failures.

The character of sagger failures may be briefly classified as follows:

1. Breakage due to the rough handling of the unburned saggers in placing in the kiln.

2. Breakage due to the too rapid heating of the saggers during the first burning.

3. Breakage during the cooling in the kilns.

4. Breakage due to rough handling of the saggers in drawing from the kiln and emptying and in again placing in the kiln.

5. Failures due to the deformation of the loaded saggers at the maximum kiln temperatures.

Taking up in order the above types of failures:

1. **Breaking in Handling.**—The breakage in the green state during placing may obviously be reduced by more careful supervision of the placing of the unburned saggers in the kiln. This breakage is, however, governed to a large extent by the strength of the sagger clays in the dried condition and clays having good strength should be used—all other properties being satisfactory. The strength in the dry condition is also governed by the size and proportioning of the grog particles and the percentage of grog used.

2. **Breakage in Heating-up.**—Some of the breakage of saggers may be ascribed to their being too rapidly heated during the first burning. This is especially true if the saggers have not been thoroughly dried before placing in the kiln. It is also governed to a certain extent by the amount of rapid heating which the clays used in the sagger mixture will withstand. The writer has observed instances in which the facilities for drying the saggers were entirely inadequate and, when placed in the kiln, they still contained an appreciable percentage of the water used in tempering the sagger mixture. In starting up the fires in the kiln, this water may be too suddenly converted into steam and cracking of the saggers results.

We must not lose sight of the fact that sagger clays contain chemically combined water, as do all other clays, and that this combined water is only driven off as the kiln reaches a visible red-heat. If the temperature is raised too rapidly during this period the chemically combined water is converted too suddenly into steam, a strain in the sagger is set up, and cracking and breakage result.

3. **Breaking in Cooling.**—From the observations we have made, we are inclined to believe that most of the breakage of saggers takes place during the cooling down of the kilns. Any clay product will crack if cooled rapidly enough. Some, of course, will crack or break more readily than others. Of the many ceramic wares, fused quartz has perhaps the greatest resistance

to temperature changes—this being due to its very low coefficient of expansion and its very regular and uniform expansion and contraction when heated or cooled. A piece of fused silica ware will crack, however, if cooled quickly enough. We find the same to be true of all ceramic wares which must necessarily withstand unusual temperature changes in use. We might mention chemical porcelain, Marquart porcelain, gas mantle rings, spark plugs, etc. Turning to the heavier and cruder clay products, manufactured from fire clays, we find the same to be the case. It is well known that silica brick are very sensitive to temperature changes and crack very readily. It is generally accepted that a fire brick having a high content of quartz or silica will crack and spall more readily than the so-called high-clay fire brick. We also know that some high-clay fire brick are more sensitive to temperature changes than others. Therefore, under the same conditions of cooling, saggers made from one fire clay mixture will crack more readily than saggers made from another mixture. We will discuss the reasons for this later on in the paper.

4. **Breakage from Handling.**—Some of the sagger breakage is undoubtedly due to the more or less rough handling which the saggers receive in placing in and drawing from the kiln. This breakage may be aggravated by the use of a vitrifying wad-clay and the consequent necessity of pounding the sagger in order to loosen it from the one underneath. It may also take place in setting the sagger on the floor or on the bench. A sagger may not be actually broken by the handling but it may be so weakened that it will crack and break the next time it is fired. Obviously, the reduction of breakage from this source is a question of using the right kind of wad-clay and of supervision of the drawing from and placing in the kiln.

5. **Deformation.**—Failures through the deformation of saggers —due either to heavy loading or firing to high temperatures— are not so common as those due to cracking or breaking. This type of failure, of course, is more prevalent in those plants firing large and heavy wares and in those plants employing the higher firing temperatures. Our American pottery practice differs markedly from that of Continental Europe in the firing tem-

peratures employed—which are uniformly lower in our ceramic plants. We might say that the average firing temperatures of our kilns is not above cone 10 or 11 and very rarely in this country do we encounter firing temperatures above cone 13 as against cones 16, 17, and 18 reached in Europe. Our sagger problem is, therefore, not analogous to theirs. We must repeat, therefore, that deformation is not the most general type of failure of saggers.

Requisite Properties of Saggers.

Having discussed the character of sagger failures we take up the question of the properties requisite in saggers in order to reduce the failures due to the above. The requisite properties of a sagger may be outlined as follows:

1. Refractoriness.
2. Mechanical strength.
3. Resistance to deformation.
4. Resistance to temperature changes.

1. Refractoriness.—The refractoriness of the clays used in a sagger mixture should receive first consideration. Refractoriness has come to mean more than a high melting or softening point.

The investigations on fire clays during the past ten years have led to a very definite classification of our fire clays, not only in accordance with their so-called melting points, but also on the basis of their vitrification or burning behavior at the temperatures at which they are to be used. The fact that one fire clay has a softening point two or three cones higher than that of another fire clay does not necessarily mean that the former will give better service in a sagger mixture. If a kiln of ware is being fired to cone 12, it is immaterial whether the saggers used have a melting or softening point of cone 29 or cone 32. In this case the behavior of the sagger at cone 13 and below is of infinitely more importance than is its behavior at cone 26.

Sagger clays, and all fire clays used as a bond in the manufacture of clay products, may be roughly divided into two classes, insofar as their burning behavior is concerned, *i. e.*, they may be classified as *vitrifying* and *open-burning*. A vitrifying clay is, of course, one which vitrifies at a comparatively low temperature

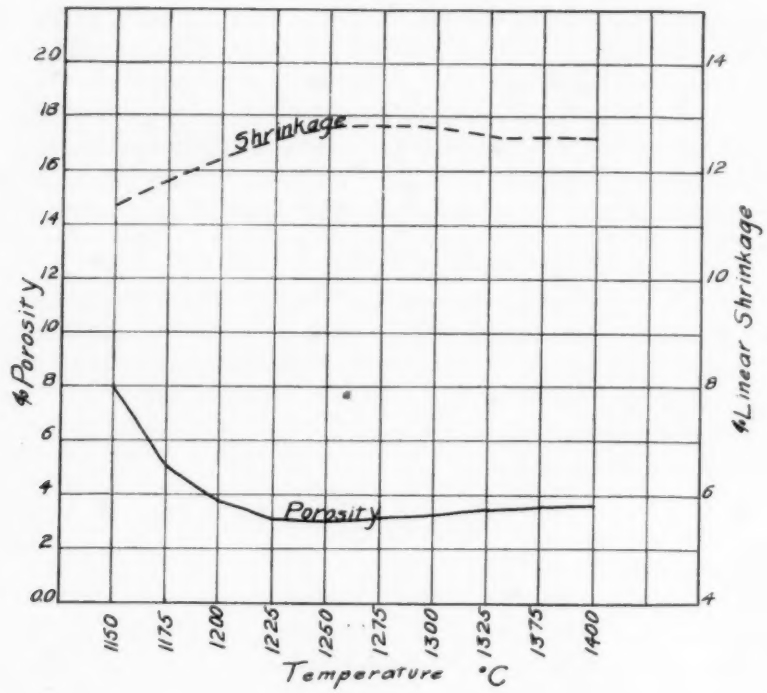

FIG. 1.

and retains its vitrified structure and low porosity over a wide temperature range without swelling or over-burning. In Fig. 1 is shown the burning behavior of a clay of this type. It will be noted that the shrinkage of this clay although high is quite uniform and that the trend of the shrinkage curve conforms quite closely with that of the porosity curve.

In Fig. 2 is shown the burning behavior of an open-burning clay—one which retains a porous structure and high absorption at a comparatively high temperature. The burning shrinkage of this type of clay is usually low and shows little change in firing over a wide temperature range.

In Fig. 3 is shown the burning behavior of a clay which does not fall under the above classification. It will be noted that the porosity of this clay decreases quite regularly with the firing

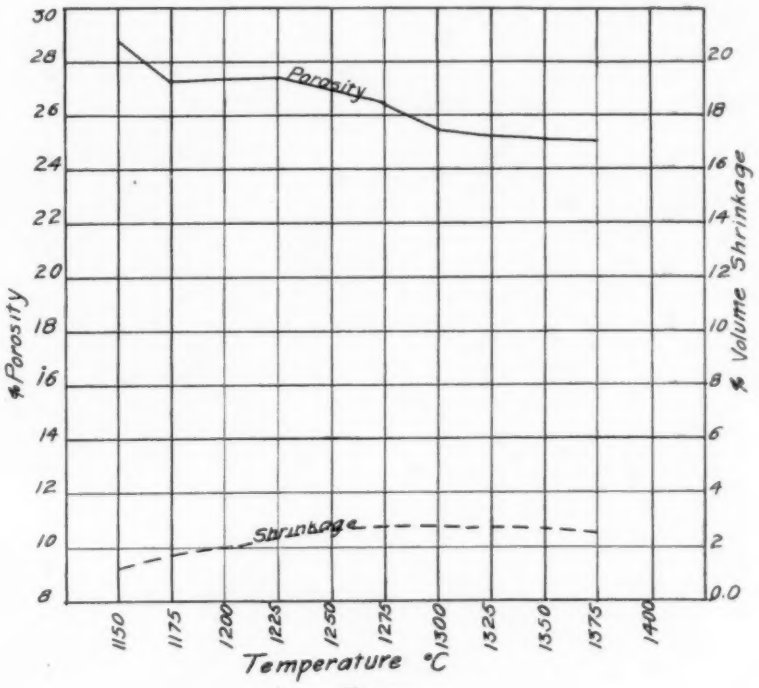

FIG. 2.

temperature until a vitrified structure is attained at a high temperature. The firing shrinkage increases quite regularly with the firing temperature and the shrinkage curve conforms with the porosity curve, *i. e.*, as the porosity decreases, the shrinkage increases. A clay of this type is obviously not well suited to the manufacture of many of our clay products as with each increase in temperature the clay undergoes further shrinkage and consequently does not reach a condition of equilibrium until a high temperature is reached.

In Fig. 4 is illustrated the burning behavior of a clay which is obviously unsuited to the manufacture of saggers or other clay products which are burned to high temperatures. It will be noted that the porosity of this clay decreases somewhat uniformly with the increase in temperature until it reaches the

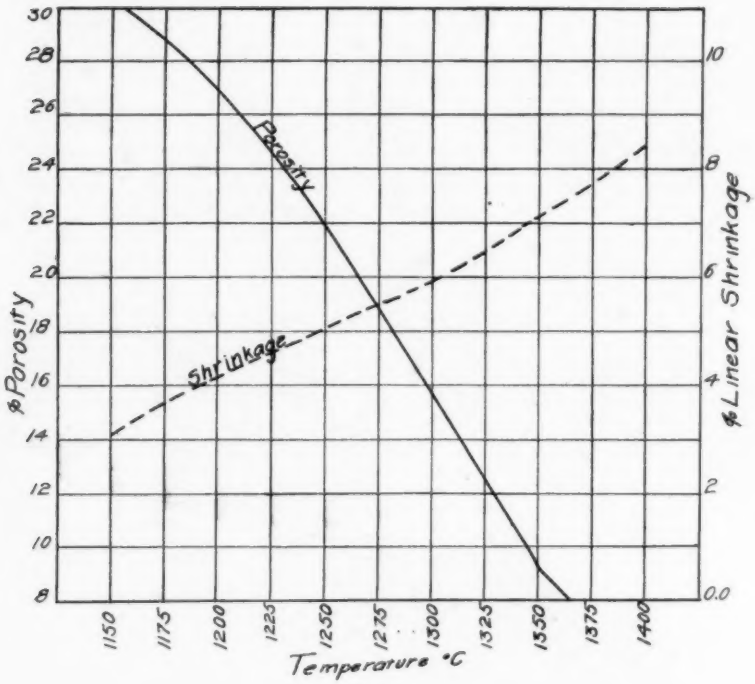

FIG. 3.

minimum porosity, after which the porosity increases rapidly, indicating the development of a vesicular structure.

In view of the wide variations in the burning behavior of the different fire clays, the softening or fusion point is therefore not a safe criterion in the selection of a clay to be used in a sagger mixture.

2. Mechanical Strength.—Under mechanical strength we will consider the resistance of the saggers to breakage during placing and drawing after the first firing. The mechanical strength of a burned sagger in the cold is dependent upon several factors:

1. The extent to which the bond clays vitrify at the finishing temperature of the kiln.

2. The mesh of the sieve through which the grog is sieved and the proportioning of the grog particles.

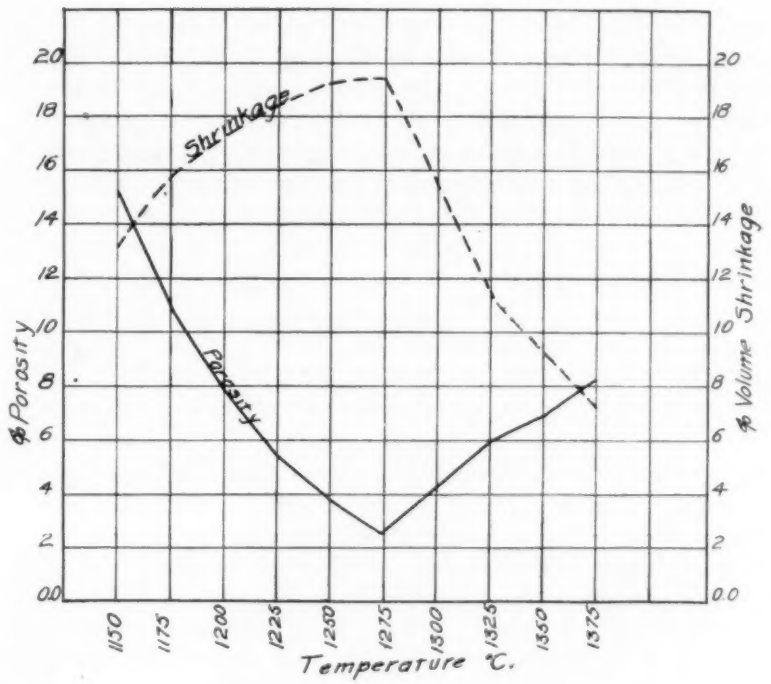

FIG. 4.

3. To the presence or absence of hair cracks—small cracks so often developed by sagger mixtures in drying and burning.

4. The proportion of grog to raw-clay used and the uniformity of mixing and tempering.

1. *Bonding Clays.*—A certain amount of vitrifying bond clay is necessary to the production of a sagger of good mechanical strength in the cold. By the sole use of an open-burning bond clay the particles of grog are held loosely together and weak saggers result. By the use of a vitrifying bond-clay the grog particles are held firmly together. The use of a certain amount of a vitrifying bond-clay having a burning behavior similar to that shown in Fig. 1, is desirable in order to secure a sagger of the desired strength. The greater the amount of vitrifying bond clay used the greater will be the strength of the resultant saggers.

It is not desirable to use too much of the vitrifying clay. In order to secure a sagger of the desired openness a certain amount of open-burning clay, having a burning behavior similar to that shown in Fig. 2, must also be used. By confining our mixture to grog, a vitrifying clay and an open-burning clay, and by varying the proportions of the two clays, we can secure a sagger of any desired mechanical strength in the cold. A good proportion is, say 50 per cent grog, 20 per cent vitrifying clay and 30 per cent open-burning clay.

2. *Sagger Grog.*—It has been our experience that too little attention has been paid to the screening of grog for sagger mixes and that our knowledge of the best practice is limited. The work of F. A. Kirkpatrick[1] on the effect of the size of grog in fire clay bodies has thrown considerable light on this subject. In a sagger mixture in which there is a preponderance of large sized grog particles, the spaces between the grains are filled with the bond clay which, in vitrifying, allows the particles of grog to slide upon each other. Instead of having a skeleton of grog particles touching at many points and held together by the bond clay we have a matrix of bond-clay in which are imbedded the grog particles and the bond-clay becomes the predominating factor in the behavior of the mixture.

The proportions of the sizes of grog particles secured by screening through a single sieve are very irregular—this being especially true if a sieve of large mesh is used. As an illustration, a grog which was prepared by passing through a $^3/_8$ mesh sieve had the following proportions of different sized grains:

3/8 – 1/4 mesh	36 per cent
4 – 8 mesh	30 per cent
8 – 12 mesh	10 per cent
12 – 20 mesh	9 per cent
20 – 40 mesh	8 per cent
Through a 40 mesh	7 per cent

It will be noted that in this grog the larger particles predominated and very little shaking caused the finer particles to settle out leaving a skeleton of coarse grains.

[1] *Trans. Am. Ceram. Soc.*, **19**, 268–300 (1917).

3. Hair Cracks.—We have often observed the small hair cracks in saggers, sometimes present in the green sagger before burning but more often observed in the burned saggers. These hair cracks may be caused by the use of a too large-mesh screen in sieving the grog, to improper proportioning of the grog particles, to the use of a bond clay which has an excessive drying and burning shrinkage, or to a combination of the above causes. If there is a preponderance of large sized grog particles there will be an excess of bond clay between the grog grains, and the bond clay, having a greater shrinkage than the grog, decreases in volume and pulls away from the grog particles causing a strain and producing the small cracks which are bound to decrease the mechanical strength of the sagger. The qualities imparted by coarsely ground grog in the sagger mixture may be more than offset by improper proportioning of the grog grains and the resultant unsound structure produced by the small hair cracks.

The general practice in Europe—employed to a limited extent in this country—of grading the particles of sagger grog into different sizes and then adding definite proportions of each size to the sagger mixture is an excellent one. In this way the voids between the larger sized grog particles are filled with smaller sized grog particles and so on until we have a skeleton of grog particles held together by the bonding clays. A mixture of this kind will have a smaller drying and burning shrinkage and greater mechanical strength when burned than a similar sagger mixture in which there is a preponderance of the larger sized grog particles.

3. Resistance to Deformation.—As we have previously stated, failures due to deformation of the saggers appear to be fewer than the losses due to breakage.

The causes of the deformation of fire clay bodies in general and in particular of fire brick have been very thoroughly studied—especially by the Bureau of Standards.[1] We are all more or less familiar with the load test as applied to fire brick when heated to high temperatures. The behavior of a fire brick when weighted down or loaded is analogous to the behavior of a sagger when filled with ware. In the case of the fire brick it has been found that the deformation under a load is largely due to the softening

[1] Bur. Standards, *Tech. Paper* 7.

of the bonding clay used in holding together the particles of grog. A vitrifying clay softens and deforms more readily than an open-burning clay and hence, if our saggers are failing through bending or deformation, the remedy is to use a smaller percentage of vitrifying clay, or to substitute a refractory open-burning clay for some or all of the tight-burning clay used in the sagger mixture.

4. Resistance to Temperature Changes.—A large proportion of sagger breakage appears to take place during the cooling down of the saggers in the kiln. It has been well established that a very dense vitrified fire clay body has less resistance to temperature changes than a fire clay body retaining an open structure after burning. A sagger mix prepared from a dense grog and excessive quantities of vitrifying bond clay is bound to be very sensitive to changes in temperature. The structure of the sagger should be as open and porous as possible without sacrificing its mechanical strength in the cold. This, of course, is governed by a proper proportioning of the contents of open-burning and vitrifying bond clay used in the mixtures.

The cracking and breaking of saggers is undoubtedly in many instances due to the use of open-burning bond clays, having a high content of sand. The practice of adding sand to a sagger mixture is not a sound one from the information which is available. The sensitiveness to cracking of all clay products containing a high percentage of silica is well known.

Silica brick, which contain from 93 to 98 per cent silica, are particularly sensitive to changes in temperature and for this reason are not used in a great many furnaces which are heated up and cooled down intermittently. We have encountered a greater tendency in the so-called quartzite or siliceous refractories to crack and spall than is observed in the so-called high clay refractories. We know that red-burning clays, containing a high percentage of sand, used in some localities in the manufacture of common building brick, are very sensitive to cracking if cooled down quickly in the kilns. By the introduction into a sagger mix of an open burning bond clay having an excess of free sand, we are inviting cracking and breaking of the saggers—through the inability of the sagger as a whole to withstand the volume changes of the particles of sand introduced in the bonding clay.

The irregular thermal expansion and contraction of the different forms of silica is the source of trouble in the manufacture of a great many of our ceramic wares. It has given trouble through the cracking and "dunting" of terra cotta, of vitreous and porcelain sanitary ware, fire brick, and in every clay product in which there is an excess of silica, either in the form of sandy fire-clays or in the form of flint as in our white burning pottery products.

We would, therefore, expect that the introduction of an excessive amount of sandy clay into a sagger mixture is very liable to cause cracking—followed by breaking of the sagger either in the same or in the succeeding burn.

Raw Materials and Composition.

In view of the above, therefore, it is not sufficient that we know the burning behavior of our sagger clays—whether vitrifying or open-burning. We must also know something of their composition, especially as regards their content of coarse or even very fine grained sand or silica. Obviously, the sagger should be as free from iron as possible and from all granular materials which are liable to cause popping or spitting-out.

It is significant that, in the manufacture of ceramic products which are particularly designed to withstand temperature changes and especially of the higher grade wares, it has been found necessary to eliminate silica in the form of flint from the body mixtures. We may mention particularly the porcelain tubes used in insulating the thermocouple wires of pyrometers. The well-known Marquarat[1] tubes are known to have a high content of alumina and little or no free silica was used in the preparation of the body. The same is true of the porcelain pyrometer tubes now being manufactured in this country. Flint has been eliminated from the body and calcined aluminous mixtures have been substituted in its place. Flint has also been found objectionable in the special porcelains which are subjected in use to temperature changes—such as gas-mantle rings, porcelain insulators, etc.

Attention should be called to the use of kaolin in sagger mixtures. In addition to being highly refractory and open burning,

[1] *Trans. Am. Ceram. Soc.*, **18**, 268 (1916).

the kaolin does not contain excessive amounts of sand as do the sandy open-burning fire clays. Very satisfactory refractory bodies have been prepared from mixtures of kaolin, vitrifying fire clay and grog. The mixtures have low drying and burning shrinkage, and have great resistance to deformation at kiln temperatures The use of kaolin, however, is not necessary providing we can secure a clay which retains a high porosity at the firing temperature. Deposits of secondary kaolin occur in this country, which, although they may not be satisfactory for use in the manufacture of high grade pottery, would be very valuable in the manufacture of saggers. We have found that the addition of kaolin in amounts as low as 10 per cent materially improves the refractoriness and other qualities of sagger or other mixes.

The composition of the grog used in a sagger mixture is governed, of course, by the composition of the raw clays used in the mixture, *i. e.*, if the grog is prepared by the crushing of old saggers the addition of a small quantity of kaolin into the mixture tends to maintain the refractoriness of the grog.

Preparation of the Mixtures.

Although most of our sagger mixtures are prepared by the soaking pit method, we would call attention to some of the advantages of using the ordinary wet-pan in mixing and tempering sagger mixtures. We have found that by the use of a wet-pan a much more uniform mixing of two or more clays is secured than by the use of a soaking-pit. The soaking-pit method depends upon the slaking down of the clays in water. If our sagger clays slake down readily in water the soaking-pit method is not so objectionable. However, we know that some fire clays will remain in water for a long time without slaking down. Clays of this kind should not be used in batches prepared by the soaking-pit method. The writer has seen saggers, made from a mixture of red and buff clay and grog mixed by this method, in which the red and yellow particles of the bond clays used could still be distinguished in the molded sagger. The use of the pug-mill in connection with the soaking pit does not always overcome the objections to the

soaking-pit method of preparation. The heavy mullers of the wet-pan crush the particles of clay and thoroughly blend the two or more clays used in the mixture.

We have also found that by the use of the wet-pan a larger percentage of grog can be introduced into the sagger-mixture without the loss of its necessary working qualities. This is accounted for by the fact that the wet-pan develops the maximum plasticity of the bond clays and hence increases their carrying capacity for grog. The advantage of the increased grog content is the lower shrinkage of the mixtures. Saggers prepared from wet-pan mixes also mold better and with smoother surfaces.

Objections have been raised to the wet-pan method on the grounds that the heavy mullers of the pan crush the larger particles of grog and make it too fine. This objection may be overcome[1] by the use of a wet-pan having mullers which are raised slightly off the bottom of the pan. By the use of a pan of this type, the particles of grog slide underneath the mullers without being crushed.

Summary.

In summarizing, we may say, therefore, that the length of life of saggers is influenced by a great many factors, not the least of these being the necessity of care in the preparation of the mixtures and in the drying and first burning of the completed saggers.

In order to produce a sagger giving maximum service, a thorough knowledge of the composition and burning behavior of the clays used in the sagger mixture is necessary.

DEPARTMENT OF CERAMICS,
RUTGERS COLLEGE.

[1] *J. Am. Ceram. Soc.*, 1, 18 (January, 1918).

MAGNESIA WARE.

By Trygve D. Yensen.

Readers of Mr. Ferguson's recent note in This Journal[1] on the Sintering of Magnesia, might get the impression, quite unintentional on the part of the author, that the world is and has been absolutely dependent upon Germany for magnesia ware. It is true—as far as the writer is aware—that magnesia wares, such as crucibles and tubes of American manufacture, have not thus far been sold in the open market in this country, but it has been produced in considerable quantities in metallurgical laboratories. The process of manufacture—although requiring electrical furnaces of considerable capacity—is quite simple, and has been fully described in the technical literature.

More than ten years ago, Dr. C. F. Burgess, who was then connected with the University of Wisconsin, obtained a patent on a process of manufacturing MgO crucibles, consisting in placing crushed or powdered MgO, previously sintered or fused, in a graphite mold, the inside part of which was split so as to form a heating element through which an electric current could be passed for the purpose of heating the magnesia to a sintering temperature. It is not known whether this process was ever successfully applied. The author has tried forming magnesia crucibles without the use of binders by means of graphite molds heated in an electric furnace to 1800° C. While the product was strong and sound there was strong evidence of reduction of MgO by the graphite of the mold, with the result that the crucible was not uniform and furthermore that the inside of the mold was consumed to such an extent that it could be used only once. It is supposed that similar difficulties were encountered by Dr. Burgess in the application of his patented process. However this may be, magnesia was fused at the University of Wisconsin and the fused MgO crushed and made into magnesia crucibles before 1910.

[1] J. B. Ferguson, "Note on the Sintering of Magnesia," *J. Am. Ceram. Soc.*, 1, 439 (1918).

The work has been continued since that time by Watts,[1] Kowalke and others, and magnesia crucibles have been in common use there.

Since 1912 the author has been making magnesia crucibles for laboratory purposes almost without interruption. A description of the method used was first published in 1914.[2]

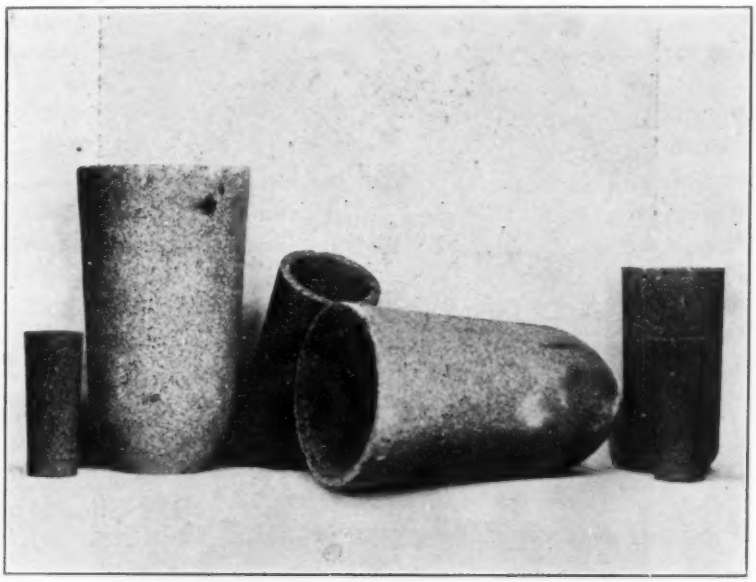

FIG. 1.

Calcined magnesite was fused in an electric arc furnace, the fused MgO crushed to go through a 40-mesh screen, then mixed with about 5 per cent hydrated magnesia, molded into crucibles in a steel mold, dried and finally heated to 1800° C in an electric furnace. The crucibles thus made were uniform, strong, had little shrinkage and showed no sign of softening at 1800°. Chem-

[1] O. P. Watts, "Making Magnesia Crucibles," *Wisconsin Engineer*, **17**, 64 (1913).

[2] Yensen, "Magnetic and Other Properties of Electrolytic Iron Melted in Vacuo," Eng. Expt. Sta., University of Ill., *Bull.* **72**, appendix 1, 49–51 (1914).

ical analysis showed the finished product to contain about 95 per cent MgO, the remainder being chiefly SiO_2, Fe_2O_3 and Al_2O_3. A purer product of still higher refractoriness could be obtained by using a purer material to start with, but for the purposes intended by the author the above amounts of impurities caused no trouble.[1]

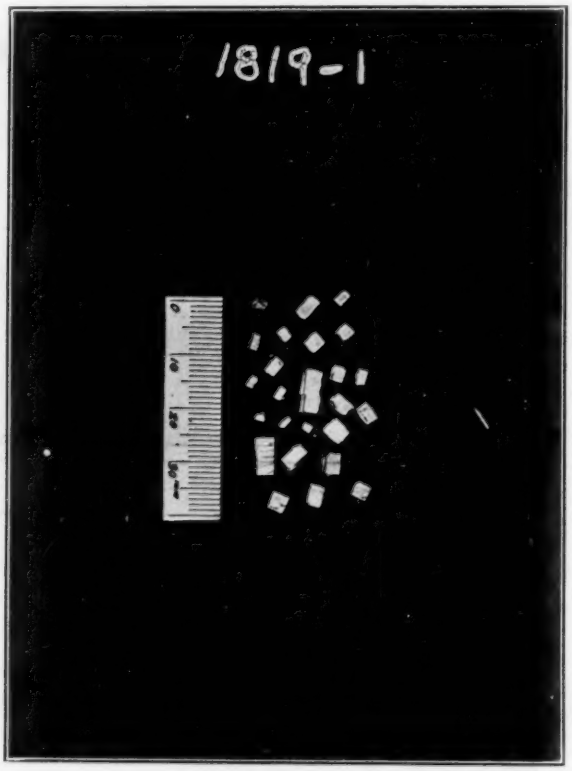

FIG. 2.

During the last two years magnesia crucibles of various sizes have been made in considerable numbers at the Westinghouse Research Laboratory, a description of which was published last year.[2] A photograph of some of these crucibles is shown in Fig. 1. The method used is essentially the same as that employed at the University of Illinois.

[1] Results published by the Bureau of Standards show that the melting point of pure MgO is 2800° C, Bur. Standards, *Sci. Paper* **212**, June, 1913.

[2] Yensen, "Preparation of Pure Alloys for Magnetic Purposes," *Trans. Am. Electrochem. Soc.*, **32**, 176 (1917).

The author has made attempts to persuade manufacturers of refractories to take up the manufacture of magnesia ware such as crucibles and tubes, but thus far without success. It seems as though the manufacturers are not yet convinced that there is a sufficient market for this kind of ware to warrant going into the business, and yet there is no product on the market today that can be used as a successful substitute for it as a container for the purpose of melting pure iron and iron alloys. Until some progressive manufacturer can be persuaded to hazard the undertaking, it seems therefore probable that each individual user will have to manufacture his own magnesia crucibles.

It has recently been brought to the author's attention that crystals of MgO may be of value for certain optical purposes. Large crystals were separated from pieces of fused MgO and examined by Dr. P. G. Nutting who found these crystals to be cubical and isotropic and to have very high refractive index and low dispersion—properties that indicate valuable lens material. This phase of fused magnesia has been described in detail by Dr. Nutting at the Baltimore Meeting of the Optical Society, December 27th. A photograph of some of the crystals is shown in Fig. 2.

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ACTIVITIES OF THE SOCIETY.

Action by the Board of Trustees.

The motions listed on page 587 of the JOURNAL as pending have been passed by the Board without further amendment, except in the case of motions 3 and 5 in the list proposed by the President. These have been amended and passed in the following form:

3. "That, as of the date of November 1, 1918, fifty (50) copies of each volume of the Transactions be reserved for sale in complete sets only, and that the Secretary be instructed to purchase at five dollars ($5) each, sufficient copies to bring the total stock of each volume to that figure. It is the sense of this resolution that a complete set shall mean nineteen Volumes, Nos. 1 to 19, inclusive, of the "Transactions of the American Ceramic Society."

5. "That copies of the volumes of Transactions and of the Journal shall be furnished to members who have or shall allow their dues to become delinquent only after the number reserved for sale has been provided. Furthermore, that in cases in which the volume that should be furnished in consideration of a certain year's dues is not available, the member shall have the option of selecting any available volume, or paying only the difference between his annual dues and the price to members of the Volume or the subscription price of the JOURNAL to members.

ACQUISITION OF NEW MEMBERS DURING DECEMBER, 1918.

Associate.

Dr. P. G. H. Boswell, The University, Liverpool, England.
S. Paul Ward, Rancagua, Chile, South America.
J. S. Laird, University of Michigan, Ann Arbor, Michigan.
Harry W. Fenton, Akron Smoking Pipe Co., Mogadore, Ohio.

J. E. McAllister, J. L. Mott Co., Trenton, N. J.
Frank E. Lauer, 2389 Mance St., Montreal, Canada.
J. P. Callaghan, Sharon Clay Products Co., Sharon, Pa.
C. B. Young, Ohio State Brick & Stone Co., Newark, Ohio.
Maurice A. Smith, McKee Glass Co., Jeanette, Pa.
Harry A. Truby, Pittsburgh Plate Glass Co., Creighton, Pa.
H. Homer Knowles, Box 427, East Liverpool, Ohio.
Fenwick D. Foley, St. John, N. B.
Paul R. Morris, 300 East 9th Ave., Tarentum, Pa.
N. B. Radabaugh, 1572 Rydal Mt. Rd., Cleveland, Ohio.

LOCAL SECTION MEETINGS.

NEW ENGLAND SECTION.

Boston, Mass., January 11, 1919.

The meeting was called to order by Chairman A. A. Klein at the Boston City Club, at 7 P.M., with twenty members present.

Mr. Klein spoke of the recent death of Mr. C. L. Walduck and his loss to the Society. It was voted that a committee be appointed by the chair to draw up resolutions and that copies be sent to his parents and to the American Ceramic Society.

Later in the evening the committee reported as follows:

"We, members and appointed representatives of the New England Section of the American Ceramic Society, in remembrance of the sterling qualities of Charles L. Walduck personally and his efficient services as Secretary of this Section, wish to record our much felt loss of him as a man and as Secretary of this Section. We extend our sympathies to his parents and recommend to our parent organization, the American Ceramic Society, a suitable obituary notice in their JOURNAL."

W G. Whitmore,
R. C. Purdy,
M. F. Cunningham.

The officers elected for the coming year were:

Chairman, W. H. Grueby, Grueby Faience & Tile Co., Boston, Mass.; *Secretary and Treasurer*, Charles J. Hudson, Norton Co., Worcester, Mass.; *Councilor*, Charles H. Kerr, American Optical Co., Southbridge, Mass.

Mr. R. C. Purdy spoke interestingly on the purpose of the Section both as regards itself and its relation to the American Ceramic Society. Two interesting and valuable talks followed:

"Some Problems of the Glass Manufacturer," by C. H. Kerr of the American Optical Company and "Clay Testing Methods and Purposes," by Carl H. Lawson of the Norton Company, Worcester, Mass. A general discussion of the papers followed.

During the afternoon previous to the meeting the members enjoyed a trip through the chemical laboratories of Arthur D. Little, Inc.

Charles J. Hudson, *Secretary.*

PITTSBURGH DISTRICT SECTION.

At a meeting held at the Mellon Institute, University of Pittsburgh, Pittsburgh, Pa., December 19, 1918, the merging of the former Beaver Section into the Pittsburgh District Section was completed. Morning and afternoon sessions were held.

At the opening of the morning session by-laws were adopted and the following officers were elected for the ensuing year: R. R. Hice, *Chairman*, C. R. Peregrine, *Vice-Chairman*, Thos. H. Sant, *Treasurer*, F. H. Riddle, *Secretary* and F. W. Walker, Sr., *Councilor*.

After the election of officers a varied and interesting program of technical papers was afforded as follows:

"Industrial Research," Dr. E. W. Tillotson, Mellon Institute.

"The Effect of Some Fluxes on Porcelain," F. H. Riddle, Bureau of Standards.

"The Influence of Some Ball Clays upon the Casting of Clay Wares," J. W. Wright, Bureau of Standards.

"The Hydraulic Properties of the Calcium Aluminates," P. H. Bates, Bureau of Standards.

"Note on the Electrical Resistance of Porcelains at Temperatures up to 800° C," A. V. Bleininger, Bureau of Standards.

Members desiring to become affiliated with the above Section should communicate with the Secretary, F. H. Riddle, Bureau of Standards, 40th and Butler Sts., Pittsburgh, Pa.

The Journal of the American Ceramic Society

THIS JOURNAL, the official organ of the American Ceramic Society, appears at this time to fill a need of the American Ceramic Industries.

It is to be published monthly, and for this reason embraces a wider field of activity than the volumes of the Transactions which it succeeds, and thereby offers greater opportunities of service to Ceramic Science and Industry.

The success of this Journal will depend upon the efforts of the individual members. Your contributions, your discussions and your suggestions, are necessary; but above all, your assistance in securing new members for the Society and subscribers to the Journal is of prime importance. The Committee on Publications therefore requests that each member of the Society be personally responsible for securing all possible members and subscriptions in his own city or town.

The subscription price is—$6.00 per year to non-members.

The annual membership dues of the Society, five dollars per year, include subscription to the Journal.

The public library, the librarians of the nearby universities, colleges or other institutions, as well as individuals who are, or ought to be, interested in the work of your Society are your objectives.

Use the application blanks at the bottom of this sheet for enrolling members and subscribers. Applications should be mailed to Prof. Charles F. Binns, Alfred, N. Y.

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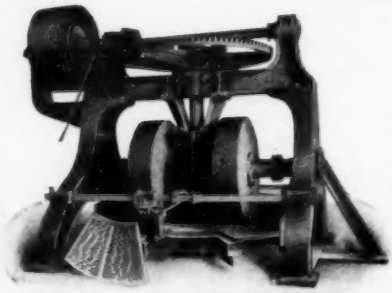

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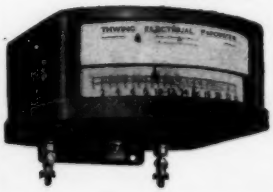

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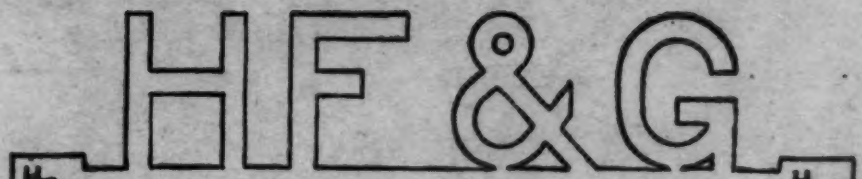

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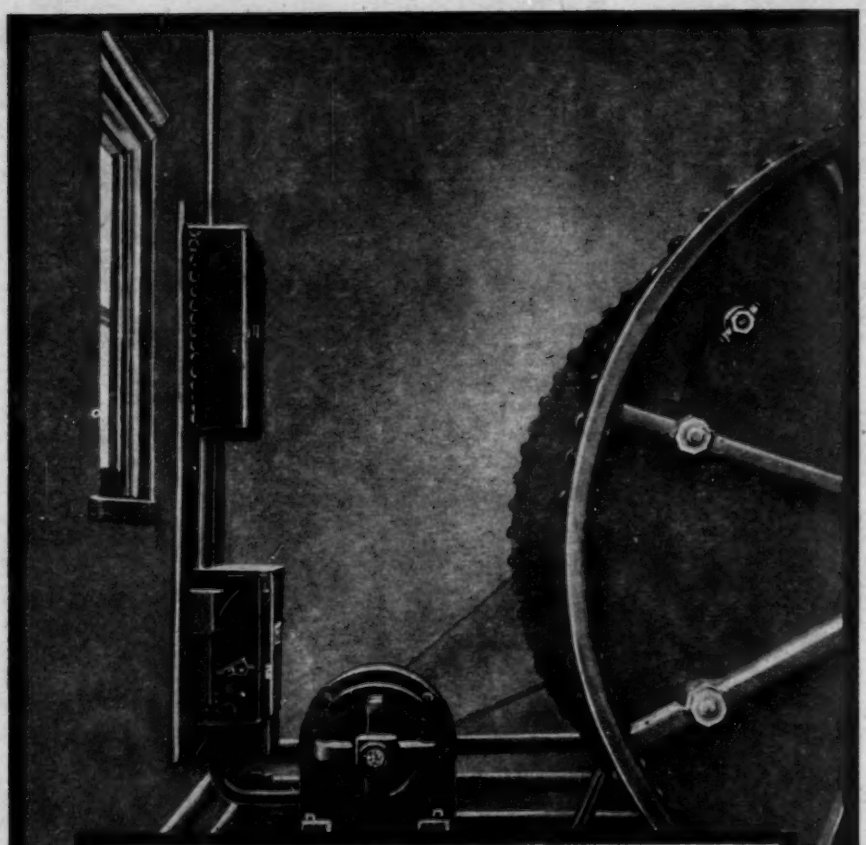

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